

# ENDEAVOUR



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## ENDEAVOUR

The British quarterly scientific journal ENDEAVOUR was first published, by Imperial Chemical Industries Limited, in January 1942. Its purpose is to provide scientists, especially those overseas, with news of the progress of the sciences. While emphasis is laid upon British work, narrow insularity is avoided by publishing a number of articles from overseas contributors and by impartial reference to the world's scientific literature. To make the journal truly international in character it is published in five separate editions—English, French, German, Italian, and Spanish.

No charge is made for ENDEAVOUR. It is distributed to senior scientists, scientific institutions, and libraries throughout the world, the guiding principle being that of helping scientists overseas to maintain those contacts which their British colleagues have always so much valued. Within these limits the Editors are at all times glad to consider the addition of new names to the mailing list.

*The drawing on the cover is of the bark Endeavour, which, commanded by Captain James Cook and carrying a number of scientific workers, was sent out by the British Admiralty in 1768 to chart the South Pacific Ocean and observe the transit of Venus*

# ENDEAVOUR

A quarterly review designed to record the  
progress of the sciences in the service  
of mankind

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# The amateur in science

In these days science is so largely the province of those who make it a lifelong profession that there is a tendency to look upon the efforts of the amateur as undeserving of serious attention. In fact, however, the amateur—by which in the present context is meant one for whom the pursuit of science is a secondary activity in life—has not only made many outstanding contributions in the past but can still play a part even today.

Historical examples abound. Thus on 19th November 1764 the senate of the university of Cambridge unanimously elected to the chair of chemistry a man who, on his own confession, ‘had never read a syllable on the subject, nor seen a single experiment’. This was Richard Watson (1737–1816), afterwards bishop of Llandaff. The action of the senate neither excited nor called for unfavourable comment. In those days the body of scientific knowledge was so limited that, given intelligence and application, a novice might in a year or two acquire sufficient mastery of chemistry or most other branches of science to make his appointment to a chair reasonable. In this particular instance the choice turned out well; Watson possessed ability of a high order, had been second wrangler, and before very long was discharging his professional duties with dignity and efficiency.

Even as late as the second half of the eighteenth century no long period of training was necessary to bring a man to the frontiers of science, and the ingenious and inquiring amateur might reasonably hope by his own efforts to advance those frontiers a measurable distance. There were, indeed, comparatively few openings for the professional scientist, and many, perhaps the majority, of the most striking scientific discoveries dating from before the nineteenth century had been made by men who, as far as science was concerned, were amateurs—though many of them were mathematicians, physicians, or apothecaries.

With the rapid growth of science and technology in the period following the industrial revolution, conditions gradually changed. There were now increasing demands for full-time scientists, and the knowledge required of them necessitated more study and practical experience than could be afforded by those whose principal activities lay in other fields. Concurrent with the accelerating expansion of knowledge was an increase in the material equipment necessary, or at least very desirable, for the successful prosecution of such

sciences as chemistry and physics. In these regions diminishing opportunities led to a diminution in the amount and importance of amateur contributions, but other fertile provinces were still open. The tendency of the amateur was now to gravitate towards the less highly specialized and less technical sciences, particularly geology, botany, and zoology, and a great deal of very valuable work was here accomplished by non-professional enthusiasts during the nineteenth century.

Geology had an irresistible fascination for a civil engineer and estate steward named William Smith (1769–1839), who used the opportunities afforded him by his profession to make extensive investigations on stratigraphy. Here the brilliant work of an amateur needs no recounting: his methods of identifying strata by their fossil contents, and his geological maps of Britain, made him the ‘father of British geology’. Smith was in fact the founder of stratigraphical geology.

On the other side of the English Channel similar fame was won by the Provençal elementary school master Jean Henri Fabre, who in a characteristically modest way devoted his exceptional powers of patience and acute observation to the study of insects, particularly the hymenoptera and coleoptera. The worth of his work, and the esteem in which it was held, are manifested by the fact that his *Souvenirs entomologiques* (1879–1907) had the honour of being crowned by the Institute of France. Other continental amateurs who left their mark upon science were Wilhelm Hofmeister the botanist (1824–77), who carried out his chief work while still an assistant in a music-shop, and, in a class by himself, Gregor Mendel, abbot of Brünn (1822–84), whose experiments on inheritance in the garden pea were of basic importance in the establishment of the modern science of genetics.

Although nineteenth-century amateur science was in the main biological and geological, contributions to chemistry and the physical sciences were not altogether lacking. The fundamental reaction in the contact process for making sulphuric acid was discovered by a vinegar-manufacturer, and the removal of phosphorus from Bessemer steel was successfully accomplished on lines thought out by a police-court clerk. The early science of photography owed very much to the efforts of Fox Talbot (1800–77), scion of a noble family, who was the first to show how an unlimited number of

positive images could be made from a photographic negative, was a pioneer of instantaneous photography and photographic engraving, and in the leisure he allowed himself from his scientific pastimes became one of the first to decipher the cuneiform inscriptions of Nineveh.

The science of astronomy owes much to the amateur. William Herschel—who has been called the ‘father of modern astronomy’—was by profession a musician, and he first began to make telescopes, an activity which later became his main source of income, because he could not afford to buy them. Schwabe, whose patient observation of the sun led to the discovery of the periodicity of sunspots, was an apothecary. Carrington was another amateur who made major discoveries in this field; he was the first to observe solar flares and to remark their association with disturbances in the earth’s magnetic field. William Huggins, a pioneer in stellar spectroscopy and a President of the Royal Society, was a business man. In recent years the brothers McMath in Michigan, who were engineers by profession, designed and constructed equipment, of ingenious and novel design, for solar observation.

The question of the possible role of the amateur in modern science is worth considering, for in all civilized countries there are large numbers of intelligent laymen whose interest in science is not confined to reading about the work of professional scientists but urges them to enlarge the realm of knowledge by personal effort. What scope have they? At a first glance it would seem very little. As the years pass, every branch of science becomes more recondite in its problems and more specialized in its technique. There was a time when scientific procedure was at least broadly intelligible to any man of education, but at the present day even scientists may find the work of fellow-scientists of other persuasions as obscure as the Eleusinian mysteries. If initiates themselves find this difficulty, the amateur nervously peeping in from the outside may well feel discouragement and dismay.

Reflection will lead us to modify this sombre conclusion. In the first place, the observational, as distinct from the experimental, aspects of many branches of science are still within the amateur’s range, and such observational work has not become of less importance. Thus there have always been amateur astronomers; upon them professionals have relied to a considerable extent for observations of variable stars, searching for

and discovering comets, and discovering novae.

The more immediate phenomena of the skies, those that form the study of meteorologists, have provided another rewarding field for the amateur, although radar methods have lately become increasingly important; as a science meteorology is in its infancy and offers innumerable problems for solution. The greater the mass of authentic data it has at its disposal, the rosier will grow the prospect of solving them. Seismology is in similar case, while oceanography, even if only oceanography from the shore, is yet another fruitful field. And no one will deny that there remain many opportunities for valuable amateur field-work in geology, petrology, and petrography.

Archaeology has perhaps suffered too bitterly from well intentioned but ill endowed amateurs to evince any great eagerness in accepting their assistance, but the itch to dig shows itself in the large numbers of local archaeological societies with which Britain and other lands are liberally sprinkled. An ardent desire to serve science ought not to be rebuffed, and archaeologists are clearly acting very properly in attempting to train and discipline those anxious to be of help. Sufficiently competent part-time workers can be of great value to the science, particularly in view of the heavy cost of hired labour.

Ecology, of both plants and animals, is a further activity in which the amateur may find a satisfying and useful outlet for his energy. Ecological studies cannot be carried out in a hurry; they call for long-continued and methodical observation and make demands upon time that the professional botanist or zoologist may find it hard to meet. As in entomology, which never lacks its numerous lay disciples, accumulation of properly authenticated data by amateurs will prove of considerable worth to those engaged in the more technical study of the subject.

Many amateur scientists, however, will remain unsatisfied with mere observation. They wish to experiment, and are willing to make a modest outlay on equipment. There is much they could do with quite limited equipment. Thus an amateur need not be disheartened by sparseness of apparatus even if his taste is towards experiments in chemistry: it is said that Adolf von Baeyer rarely used any apparatus beyond the test-tube, and even if this is an exaggeration it remains true that great work has often been accomplished with very simple means.

# Mesons, hyperons, and antiprotons

H. S. W. MASSEY

Recent research, which has resulted in the identification of a new range of fundamental particles, has shattered the belief that all matter is constructed from a relatively few simple units. While the nature and significance of these new particles are far from being completely understood, and there may well exist others, it has been possible to formulate some generalizations about the factors which determine the speed and nature of atomic transformations. While the fundamental validity of these generalizations is uncertain, they nevertheless provide a convenient working hypothesis for the further exploration of this exciting new field.

The establishment of the atomic constitution of matter gave rise to the hope that it would be possible to describe the properties of all matter in terms of a few fundamental units or particles. Just before the second world war it seemed, indeed, that we were very close to realizing this hope. The chemical properties and many of the physical properties of matter could be understood in terms of atomic structure based on the Rutherford nuclear model and the laws of quantum mechanics. Only five particles seemed to be involved: three structural units, the electron, proton, and neutron, and two cements, the photon or light quantum, and the meson. Protons and neutrons formed the tightly bound, positively charged atomic nucleus around which the negatively charged electrons revolved under the influence of the electrical attraction of the unlike charge. This attraction could be represented in terms of an exchange of light quanta between the charges. Similarly, exchange of mesons between nucleons (neutrons and/or protons) was supposed to provide the attraction holding the nucleus together. In 1935 H. Yukawa [1] had predicted that such mesons should have masses about 300 times that of the electron and be electrically charged. Particles with very similar properties were discovered in cosmic rays by C. D. Anderson and S. H. Neddermeyer [2] in 1937.

One phenomenon disturbing to this conception was that of beta-radioactivity, in which energy seemed to disappear and the conservation of angular momentum to be violated. It was suggested that actually energy and angular momentum are stolen away in a beta decay process by a particle called the neutrino, with so little interaction with matter as to be unobservable with present techniques.

Soon after fundamental research in this field began again after the war it was found that this

apparently satisfactory and simple situation was an illusion. The meson which had been observed was found not to be the one required by Yukawa, although others apparently answering to his requirements were found in cosmic radiation at high altitudes. Apart from this supernumerary meson, called the  $\mu$ -meson to distinguish it from the Yukawa type  $\pi$ -mesons, others, known as  $\kappa$ -mesons, have been found recently. These mesons, though over three times as heavy as the  $\pi$ -mesons, have masses only about two-thirds that of the proton. To add to the confusion, other particles, known as hyperons, have been observed which have masses between 25 and 40 per cent greater than that of a proton or neutron.

Of all this multitude, the only ones which are stable when free are the proton, the electron, the light quantum, and, seemingly, the neutrino. All the others decay in one way or another, often by a complicated sequence of processes, into one or more of these stable particles. The neutrino seems to play an important part in many of these decay processes. It is interesting to note that the development of technique has been so rapid that within quite a short time we should know whether it does exist or not.

Although we have at present no inkling of the part played by the unexpected particles in the scheme of things, we must point out, in fairness to the theoretical physicists, that the existence of two particles with remarkable properties (apart from Yukawa's meson) was predicted theoretically. These are the positron or positive electron, and the negative proton or antiproton. Both have since been observed—the positron nearly 24 years ago, the antiproton [3] during the past few months (see page 127).

The behaviour of particles moving with high energy is in many ways very different from that of ordinary matter at ordinary speeds. Both

relativistic and quantum modifications must be introduced. We shall begin by summarizing the essential features of these modifications as they relate to the study of fundamental particles. After a brief account of the experimental techniques employed we shall conclude with a summary of the present situation.

#### MASS, MOMENTUM, AND ENERGY IN RELATIVITY THEORY

The motion of a particle can no longer be described accurately by classical mechanics when its velocity  $v$  is not small compared with that of light ( $c$ ). Thus the classical expression  $mv$  of the momentum,  $m$  being the mass, is really only an approximation to the relativistic formula  $mv(1 - v^2/c^2)^{-\frac{1}{2}}$ . This is just as if the mass varied with the velocity. The constant  $m$  is usually referred to as the rest mass of the particle.

Remarkable consequences follow when the relativistic modifications of the concept of energy are considered. The total energy of the particle is found to be  $mc^2(1 - v^2/c^2)^{-\frac{1}{2}}$ . When  $v/c$  is small this is approximately  $mc^2 + \frac{1}{2}mv^2$ , i.e. the kinetic energy of classical mechanics plus a term  $mc^2$ , which has no classical analogue. This additional energy arises from the possession of rest mass, and it suggests that energy of this kind might be transformed into other forms such as kinetic energy, radiant energy, and so on; in other words, the annihilation of matter and its reappearance as some other form of energy. Inverse transformations would also be expected in which rest mass energy, and hence matter, is created from radiant or kinetic energy. Such transformations are now commonplace in high-energy physics. They can be described theoretically only by allowing fully for both quantum and relativistic modifications of classical physics—the theory of quantized wave-particle fields, which is discussed below.

The momentum  $p$  and the energy  $E$  of a particle of rest mass  $m$  are connected through the relation

$$p^2 = \frac{E^2}{c^2} - m^2c^2 \quad \dots \dots \dots (1)$$

For a particle with no rest mass, such as the light quantum or neutrino, we have  $p = E/c$ .

#### CHARACTERISTIC PROPERTIES OF FUNDAMENTAL PARTICLES

A fundamental particle is characterized by its rest mass, charge, spin, parity, its interaction with nucleons, and its mean lifetime and modes of decay.

The spin and parity need some explanation, though we shall defer consideration of the latter until a later section. As to the spin, it is first to be noted that, according to quantum theory, angular momentum is quantized. If it arises from orbital motion round a centre of force it is given by  $\hbar\sqrt{\{l(l+1)\}}$ , where  $l$  is zero or a positive integer and  $2\pi\hbar$  is Planck's constant. It appears that particles may also possess internal angular momentum or spin which has a definite value for each particle, given again by  $\hbar\sqrt{\{l(l+1)\}}$  but with  $l$  allowed now to take half-integral as well as integral values. Particles such as electrons, nucleons, and  $\mu$ -mesons for which the spin is half-integral have certain fundamentally different properties from those, such as  $\pi$ - and  $\kappa$ -mesons and photons, for which it is zero or integral. The former are referred to as fermions, the latter as bosons, after Fermi and Bose respectively.

#### WAVE-PARTICLE FIELDS IN QUANTUM THEORY

Although we have hitherto adopted the customary convention of referring to 'fundamental particles', this is far from being a correct description in terms of modern quantum theory. We should talk instead of 'fundamental wave-particle fields'. To illustrate what is meant by this we shall discuss briefly two representative cases: that of the light quantum and of the electron respectively. These are distinguished by the fact that, in the classical limit, for light only the wave aspect remains, whereas for the electron it is the particle aspect which persists.

According to classical mechanics it is possible, given the initial values of the co-ordinates describing the system as well as the initial rates of change of these co-ordinates, to predict their values at any subsequent time, provided the forces acting on the system are known. This is not possible in quantum mechanics. The value of a quantity such as the energy or momentum characterizing the state of the system is no longer capable of continuous variation, but must be one of a set of allowed values. Moreover, it is possible to determine only what is the probability that, at some time, the quantity concerned will have any one of these values. Quantum mechanics provides the technique for determining the allowed values for any particular quantity and for calculating the probability that any one of these values will be assumed at a time  $t$ . Changes occur in the state of the system due to transitions of the quantities characterizing the state, from one set of allowed

values to another. An important task of quantum theory is, therefore, the calculation of the probabilities of observed transitions. Given the classical theory of the motions of a given dynamical system, the necessary generalization to the quantum formulation—the process of quantization—now offers no difficulty.

In the consideration of our first example, light, the quantization of Maxwell's electromagnetic field leads to the following allowed values for the field energy and momentum.

$$\text{Field energy: } \Sigma_s(n_s + \frac{1}{2})hv_s, \dots \quad (2)$$

the nature of  $n_s$  being described below.

Field momentum (in a particular direction):

$$\Sigma_s n_s hv_s/c \dots \quad (3)$$

The allowed frequencies are such that, if the field occupies a volume  $V$  the number of allowed values between  $v$  and  $v + dv$  is

$$\frac{4\pi v^2 dv}{c^3} V \dots \quad (4)$$

A state of the field characterized by the number  $n_s$  can be regarded as one in which there are  $n_s$  particles present of energy  $hv_s$  and momentum of magnitude  $hv_s/c$ . These are the light quanta already referred to. It will be noticed that, even if there are no quanta present, the field energy does not vanish. This has interesting consequences, but it would take us too far from the main theme to discuss this point further.

Emission and absorption of light may now be described as transitions between states of the field in which  $n_s$  changes. Thus emission of a quantum of frequency  $v_s$  involves a change of  $n_s$  from 0 to +1, absorption of a single quantum of the same frequency a change from +1 to 0, and so on.

In considering the electron field we must start one stage further on than for light quanta. This is because we have no classical electron field theory to work from, the electron being, classically, a particle. The first step is to quantize the classical theory of the motion of a single electron—first quantization. This introduces a continuous variable, usually called the wave function  $\psi$  of the electron, which is such that  $|\psi|^2 \delta v$  is the probability of finding the electron in the small volume  $\delta v$ . The wave function at this stage plays for the electron a role similar to that which the electromagnetic field strengths or potentials do for light quanta. A second quantization procedure may now be applied to the  $\psi$ -field, and it is found that the allowed values of the energy, momentum, and electric charge of the field are given by:

$$\text{Total energy} = \Sigma_s N_s E_s - \Sigma_s N_s E_s \dots \quad (5)$$

$$\text{Total momentum} = \Sigma_s N_s p_s + \Sigma N_s p_s \dots \quad (6)$$

$$\text{Total charge} = -e\Sigma_s N_s - e\Sigma_s N_s \dots \quad (7)$$

where  $e$  is the magnitude of the charge on an electron and  $p_s$ ,  $E_s$  are related by the relativistic formula (1). In contrast to the electromagnetic field, the numbers  $N_s$  and  $N_s$  are restricted to either 0 or 1. This restriction is a consequence of the fact that the spin quantum number for an electron is  $\frac{1}{2}$ , as against 1 for a light quantum.

When  $N_s = 0$  we have a state in which there are  $N_s$  electrons present of momentum  $p_s$ , energy  $E_s$ , and charge  $-e$ . The situation is much less clear when  $N_s = 0$ ,  $N_s \neq 0$ . This would seem to be a state in which there are  $N_s$  particles present of momentum  $p_s$ , charge  $-e$ , but energy  $-E_s$ . Such particles, possessing negative kinetic energy, would have a negative rest mass and most unfamiliar properties. Thus, when acted on by a force, they would be accelerated in the opposite sense to the force! No particles of this kind have in fact been observed. Account may be taken of this by defining the vacuum state of the electron field as one in which the occupation numbers for all states of the 'unnatural' particles have their maximum values of 1. Thus, for the vacuum:

$$\text{Total energy} = -\Sigma_s N_s E_s \dots \quad (8)$$

$$\text{Total momentum} = \Sigma_s N_s p_s \dots \quad (9)$$

$$\text{Total charge} = -e\Sigma_s N_s \dots \quad (10)$$

$$N_s = 1, \text{ all } s.$$

The magnitude of any particular quantity which will be observable for an electron field is then the difference from the value for the vacuum. Thus, subtracting (8), (9), and (10) from (5), (6), and (7) respectively, we have:

Observable total energy

$$\begin{aligned} &= \Sigma_s N_s E_s - \Sigma(N_s - 1)E_s \\ &= \Sigma(N_s + N_s^+)E_s, \\ &\text{where } N_s^+ = 1 - N_s \end{aligned}$$

Observable total momentum

$$= \Sigma(N_s - N_s^+)p_s,$$

Observable total charge

$$= -e\Sigma N_s + e\Sigma N_s^+,$$

with  $N_s = 0, 1$ ;  $N_s^+ = 0, 1$ .

A state in which  $N_s = 0$ ,  $N_s^+ = 1$  may now be regarded as one in which a particle of energy  $E_s$ , momentum  $p_s$ , and charge + $e$  is present. This particle is known as a positron or anti-electron. It can be regarded as an absence of a particle of charge  $-e$ , momentum  $-p_s$ , and energy  $-E_s$ .

Unless it is assumed that positrons can be created under certain circumstances, the difficulty

of the 'unnatural' particles would remain. The discovery of positrons by Anderson [4] and by P. M. S. Blackett and G. P. S. Occhialini [5] was a striking confirmation of the quantum theory of the electron field.

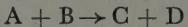
#### THE PROTON FIELD AND THE ANTIPIRON

The proton has a half-integral spin quantum number just as an electron has, so the theory of the quantized proton field follows exactly similar lines. In particular, the theory requires the existence of an antiproton bearing to the proton the same relation as the positron does to the electron. Thus the antiproton should have the same mass as a proton, but possess a negative charge,  $-e$ , in place of the positive charge of the proton.

#### FIELDS IN GENERAL—PARITY

We may similarly associate a quantized field with every fundamental particle. All those particles which have half-integral spin will have fields of the electron and proton type, with the corresponding antiparticles. Such particles are called fermions and are to be distinguished from those called bosons, which have integral or zero spin and fields of the photon type.

The parity of a wave-particle field is determined by the way the field variable transforms when the reference axes are changed from a right-handed set to a left-handed set. It must either be unaltered or changed in sign. In the former case it is said to have parity + 1, in the latter - 1. The rate of a reaction such as



must clearly be independent of the choice of reference axes, so that if  $p_A$ ,  $p_B$ ,  $p_C$ ,  $p_D$  are the respective parities of the corresponding fields,

$$p_A p_B = p_C p_D,$$

an example of the so-called conservation of parity.

#### INTERACTIONS BETWEEN FIELDS—CREATION AND ANNIHILATION PROCESSES

The various wave fields are not independent, but interact with each other. Because of this interaction, transitions may take place simultaneously between states of the two fields so that energy, momentum, angular momentum (including spin), charge, and parity are conserved. All collision or decay processes can be described in this way.

Thus consider the interaction between the electromagnetic and electron fields. A process in which an electron of initial energy  $E_i$  emits a quantum of frequency  $v$ , so that its energy is

reduced to  $E_f$ , involves a transition between states of the electron and photon field:

Initial state	Final state
$N_s = 0, s \neq i$	$N_s = 0, s \neq f$
$= 1, s = i$	$= 1, s = f$
$N_s^+ = 0, \text{ all } s$	$N_s^+ = 0, \text{ all } s$
$n_s = 0, \text{ all } s$	$n_s = 0, s \neq j$
	$= 1, s = j$

That is to say, we have annihilation of an electron in state  $i$  and creation of an electron in state  $f$  and of a photon with frequency  $v$ . Bearing in mind the conservation rules, we can see how a positron-electron pair may be materialized from a light quantum of frequency  $v_k$ . Here we have

Initial state	Final state
$N_s = 0, \text{ all } s$	$N_s = 0, s \neq l$
$N_s^+ = 0, \text{ all } s$	$= 1, s = l$
$n_s = 0, s \neq k$	$N_s^+ = 0, s \neq n$
$n_k = 1$	$= 1, s = n$
	$n_s = 0, \text{ all } s$

and  $h\nu_k = E_i + E_n$ .

Since  $E_l$  and  $E_n$  are each never less than  $mc^2$ , it follows that the threshold frequency for producing a pair is  $2mc^2/h$ . This applies to materialization of kinetic, as well as radiant, energy in the form of an electron-positron pair. For materialization of a proton-antiproton pair the available energy must exceed  $2Mc^2$ , where  $M$  is the proton mass. The inverse process of mutual annihilation of the pair will release energy not less than this.

It is because of the need to make available sufficient kinetic energy to create the rest masses of the unstable particles that this branch of physics necessarily involves high energies.

Apart from the five conservation rules mentioned at the outset, it seems likely that one other quantity is also conserved in all transformations and that a still further general restriction is imposed. These will be discussed explicitly in later sections (page 125).

As the study of fundamental particles is largely one of energy transformations, a clear and convenient choice of energy unit must be made. The choice is the electron-volt, which is the energy acquired by an electron when falling through a potential difference of one volt. It is equal to  $1.6 \times 10^{-12}$  ergs.  $10^6$  eV is usually denoted as 1 MeV and  $10^9$  eV as 1 GeV.

The rest mass of an electron is equivalent to  $\frac{1}{2}$  MeV, that of a proton to 950 MeV, and those of the mesons to intermediate values. Obviously the first necessity for research in this field is the

availability of a source of particles with kinetic energies of this order or greater.

#### SOURCES OF HIGH-ENERGY PARTICLES

Until 1947 the only available source of particles with sufficient energy to create mesons was the natural one of cosmic rays. Primary cosmic rays form  $\pi$ - and  $\kappa$ -meson secondaries in the atmosphere, mainly at a height of about ten miles above the surface. These decay to the less interesting  $\mu$ -mesons quite rapidly, so that to obtain a good yield of the interesting particles it is necessary to send detecting apparatus up as high as possible; hence the establishment of cosmic ray stations on high mountains and the carriage of nuclear emulsion detectors to upwards of 80 000 ft. by balloons.

The rapid development of artificial means of accelerating particles to high energies reached such a stage that in 1947 the cyclotron at Berkeley was able to accelerate alpha-particles to an energy (400 MeV) great enough to produce  $\pi$ -mesons. The cosmotron at Brookhaven (2.2 GeV) and the bevatron at Berkeley (6.2 GeV) now accelerate particles to energies great enough to create  $\kappa$ -mesons. The bevatron has gone even further in producing antiprotons. Plans exist for yet more powerful machines, including one designed to reach 25 GeV at the European Nuclear Physics Laboratory at Geneva. For a recent survey of high-energy particle accelerators see [10]. Accelerators have the advantage over cosmic rays in providing more intense and more homogeneous beams. However, the most energetic cosmic ray particles are still well beyond the reach of artificial production, and must still be used for studies requiring very high energies.

#### TECHNIQUES FOR STUDYING FAST PARTICLES

All techniques for studying the properties of fast particles depend upon the fact that such particles ionize the atoms of matter through which they pass. Some of the electrons ejected from the atoms may themselves produce ionization. As a rough rule, about 30 eV of energy is expended for each electron-ion pair produced. A particle with 1000 MeV initial energy can therefore produce about 30 000 000 ion pairs along its path, representing a total separated charge of about  $4.8 \times 10^{-12}$  coulombs. Because of this high ionizing power the passage of individual particles may be registered and the actual track recorded photographically.

There are four main methods of utilizing the

ionization. Three of these—the cloud chamber, the nuclear emulsion, and the bubble chamber—involve the actual photographic recording of tracks, while the fourth involves automatic counting of the number of particles with selected properties arriving at a selected location. These methods are complementary, and all have already yielded valuable results except the bubble chamber, which is a very recent invention and has not yet been in operation long enough to have made a big contribution.

The mode of operation of a Wilson cloud chamber is too well known to need much description here. It depends on the fact that condensation of vapour in a supersaturated gas can occur only when condensation nuclei are present. Ions and electrons, because of their charge, act as suitable nuclei. If a gas containing a vapour is expanded so as to produce supersaturation when an ionizing particle is passing through, condensation will take place along the track of the particle where it has produced ions and electrons. By suitable synchronization, the condensed droplets along the track may be photographed, thereby outlining the path of the fast particles. Figure 1 illustrates examples of tracks obtained in this way.

A nuclear emulsion is simply a photographic emulsion suitably sensitized so that a fast particle passing through it produces silver granules at points along its ionizing path. By a suitable developing and fixing process the track is photographed and may be viewed through a suitable microscope; figure 2 illustrates a micrograph of tracks obtained by this method.

A bubble chamber can be regarded in many ways as the inverse of a cloud chamber. It depends on the fact that a liquid heated, while under compression, to a temperature well above its boiling point at atmospheric pressure will not boil immediately the pressure is reduced to atmospheric unless suitable nuclei are present on which the bubbles can form. Charged particles are able to act as such nuclei, so that if a fast particle passes through the superheated liquid, boiling will begin along the track. Synchronized photography of the bubbles may then be used to observe the track of the fast particle. Figure 3 shows examples.

#### IDENTIFICATION OF PARTICLES FROM CLOUD CHAMBER, BUBBLE CHAMBER, AND EMULSION TRACKS

The mass of a particle may be determined, if its momentum and energy are known, from the relativistic relation (1). In principle, the momentum



FIGURE 1 - Cloud chamber photograph of the decay of a  $\tau$ -meson into three  $\pi$ -mesons. The track of the  $\tau$ -meson is indicated as O and those of the three  $\pi$ -mesons as 1, 2, 3 respectively. The photograph was taken with a magnetic field of several thousand gauss applied to the chamber, so that the track of the  $\tau$ -meson is perceptibly curved. Also visible in the photograph are tracks of greater curvature due to particles of lower momentum. (The photograph is reproduced by kind permission of the Editors of the Physical Review, and of the authors, from a paper by Burwell, Huggett and Thompson [8].)

may be determined from the curvature produced in the track of the particle by application of a strong magnetic field. This is practicable in a cloud chamber because the density of the medium through which the fast particle is passing is so low that the path is not curved appreciably by the many small deflections due to collisions with the nuclei of the medium. Fields of the order of 10 000 gauss are often employed, and these enable momenta as high as 10 GeV/c to be measured

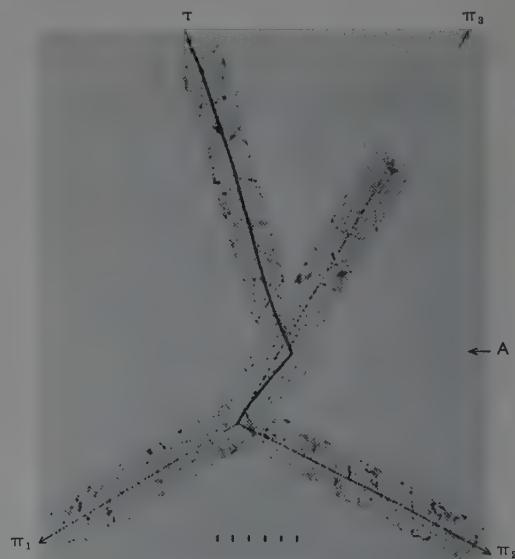


FIGURE 2 - Micrograph showing the decay of a  $\tau$ -meson in a photographic emulsion. The  $\tau$ -meson track is very dense, as the meson is near the end of its range. It suffers a sharp deviation at A, due to a collision with a nucleus in the emulsion. The tracks of the three  $\pi$ -mesons are indicated as  $\pi_1$ ,  $\pi_2$ , and  $\pi_3$  respectively. In track 1 the grain density is increasing perceptibly as the  $\pi$ -meson slows down. (The photograph is reproduced by kind permission of the Editors of the Philosophical Magazine, and of the author, from a paper by Hodgson [9]).

with reasonable accuracy. In emulsions and bubble chambers the density of the medium is too high for magnetic methods to be useful, but here the momentum may be estimated from the curvature produced by the multiple small-angle scattering.

The energy may be calculated if the range of the particle in the chamber can be measured: the range is the total length of the track before the particle is brought to rest. For particles with energies greater than the rest-energies of the more massive particles the ranges are often so long that special arrangements must be made to measure them. One very fertile device is to use two chambers, as in figure 5. The upper one is designed to measure momentum by the magnetic method, but has little effect on the energy of the particle. It passes down into the lower chamber, in which there are parallel plates of strongly absorbing material such as lead. Between these plates the track can be observed and the plate in which it stops can be identified. From this the range in lead may be obtained, and hence the energy.



FIGURE 3—Photograph of tracks of fast particles in a propane bubble chamber exposed to the issuing beam from the cosmotron. The straight tracks are due to protons or  $\pi^-$ -mesons. The arrow indicates the track of a slow  $\pi^+$ -meson which at the end of its range decays into a  $\mu^+$ -meson, which in turn decays to a positive electron, which gives the ultimate, much less dense, track. (This photograph was kindly supplied by Dr C. Dodd.)

In an emulsion the energy may be obtained from measurement of the density of developed grains along the track or from the so-called gap density, the number of gaps between grains per unit length of track. Calibration may be carried out by observations of tracks of particles of known mass and energy. The sense in which the grain density is increasing gives in any case the sense in which the particle is moving (see figure 2).

The nature of a particle forming an emulsion track may often be identified by noting what appears at the end of the track. Some decay process may have occurred (see figure 3) or the particle may have been absorbed by a nucleus of the emulsion, giving rise to a nuclear explosion or star as in figure 4. With experience, much may be deduced from these. For this reason it is an advantage to use an emulsion thick enough to bring to rest a particle produced in it. In addition, measurement of the range in the emulsion is a powerful means of determining the particle energy.

In recent years emulsion stacks made of a pile

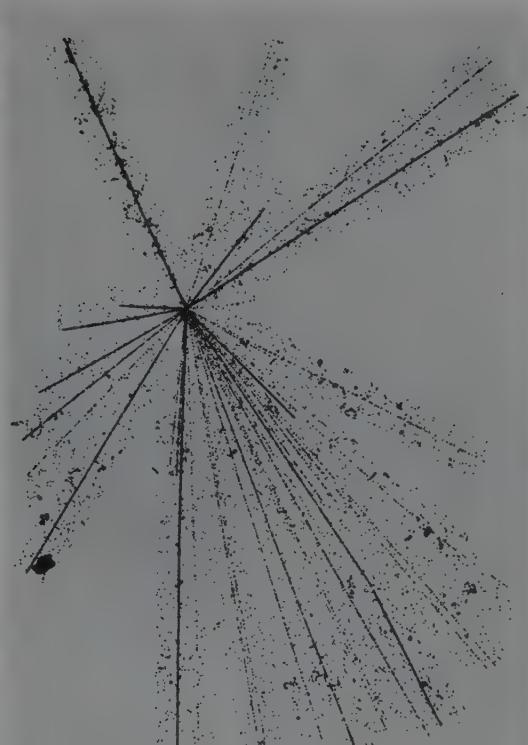


FIGURE 4—Micrograph showing a nuclear disintegration star produced by a  $\pi$ -meson. This is a characteristic event for a  $\pi^-$ -meson. A  $\mu^-$ -meson does not produce a large star, while a  $\pi^+$ -meson decays into a  $\mu^+$  (see figure 3) and a  $\mu^+$  into an electron. (This photograph was kindly supplied by Dr P. Prowse.)

of emulsions stripped from their glass backings have been used with much success. They have been flown in balloons to altitudes near 100 000 ft so as to expose them to cosmic rays. Analysis of the processed stack is a long job, and it has been organized on a basis of international collaboration.

One recent stack, known as the G-stack, consisted of 250 sheets of emulsion 600  $\mu$  thick and with superficial dimensions  $37 \times 27$  cm, weighing 300 lb. It was launched from Novi Ligure in Italy, and after a somewhat tortuous flight reached ground over the Apennines at a greater speed than anticipated, due to parachute failure. About one-tenth of the stack was destroyed, but the remainder has yielded useful results. The analysis was shared between the Universities of Bristol, Copenhagen, and Genoa, University College, Dublin, and the Institute of Advanced Studies, Dublin.

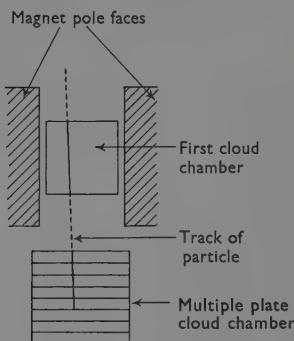


FIGURE 5.—The principle of the double cloud chamber method for determining the mass and sign of the charge of fast particles. The fast particle track is shown in full line where it is observed in the cloud chamber, and as a dotted line elsewhere.

Emulsion stacks are also of much value when used in conjunction with accelerators. By magnetic analysis it is possible to isolate from the machine a beam of particles with given momentum and allow it to irradiate a stack. Particles in this beam with a definite mass will have a definite range in the stack, and so may be separated.

#### COUNTER METHODS

A counter is a device which records the passage of an ionizing particle through it. The best known type is the Geiger counter, but for many purposes this is being replaced by the scintillation counter, which is a modern version of the original scintillation method used by Rutherford for counting alpha-particles from radioactive substances. Fast particles impinging on suitable substances, known as phosphors, produce flashes of light. These were observed visually in Rutherford's experiments, often with much difficulty and uncertainty. In the modern technique the light flashes are piped to a photomultiplier, which transforms them into electrical impulses which are automatically recorded. The sensitivity is then enormously greater and subjective influences are absent. It is also possible to obtain information about the nature and energy of the particle from the character of the electrical impulse produced.

Another type of counter depending on light emission is the Čerenkov counter. A fast particle passing through a medium with a speed greater than the velocity of light in the medium produces electromagnetic shock waves, analogous to the shock waves generated by an aeroplane flying at a Mach number greater than 1. These waves

appear as light, which may be observed by photomultiplier methods. Counters of this kind are selective as far as particle speed is concerned, and this selectivity may be increased by limiting the cone of emission of the observed light.

Counter methods are capable of high accuracy and discrimination. It is possible to make use of the great flexibility of modern electronic circuits to combine sets of counters so that the only impulses recorded are those which operate certain counters and not others. Alternatively, in addition, it may be arranged that the desired impulses are those which operate one set at a certain instant and another set after a suitable time delay, which may be as small as one microsecond or even less. Such arrangements make it possible to count selectively particles of one kind and one energy from a mixed beam. A recent illustration of these techniques in operation is the discovery of the antiproton, described later.

#### THE OBSERVED PARTICLES

These may be classified as fermions and bosons respectively (p. 118). The fermions (table I) include the electron, positron, and neutrino, the  $\mu$ -mesons, the nucleons and antinucleons, and the hyperons (table III); the bosons (table II) are made up of the photon, the  $\pi$ -mesons, and the  $\kappa$ -mesons. The last column of table I will be referred to later.

The question marks indicate possibilities as yet unconfirmed or data not yet obtained. The most remarkable recent development is the evidence that all the  $\kappa$ -mesons have the same mass. They cannot, however, represent only three particles (with positive, zero, and negative charges respectively) with various alternative modes of decay. The  $\tau$ -mesons must have different parity from the  $\Theta^0$ ,  $\kappa^+\pi_2$ , and  $\kappa^-\pi_2$  varieties. It is possible, however, that the  $\kappa$ -mesons may represent only two sets of three particles with different modes of decay; they have been provisionally called tauons and thetons respectively. Figures 1 and 2 show the decay of a  $\tau$ -meson as observed in an emulsion and in a cloud chamber respectively.

#### DISCUSSION OF THE OBSERVED DATA

It appears possible to represent all the forces occurring in Nature (apart from the force of gravity) in terms of contact interactions between certain particles. Apparent action at a distance can be regarded as arising from exchange between the interacting systems of intermediary particles with which each has contact interaction. The

strongest contact interactions are those of  $\pi$ - and  $\kappa$ -mesons with nucleons and hyperons. In some way, the details of which are not yet clear, they give rise to the forces which bind nucleons so firmly in nuclei. Next in strength are those between photons and charged particles, leading in particular to the Coulomb forces between charges. Finally, we have the weak interactions which lead to processes involving neutrino production or absorption.

The  $\pi$ -mesons are produced by the acceleration of sufficiently energetic nucleons in much the same way as photons are by the acceleration of charged particles (i.e. X-ray production by accelerating electrons). It does not seem, however, that the  $\kappa$ -mesons are produced quite so simply, but first we must note certain general considerations involving the hyperons.

#### HYPERON PRODUCTION— THE CONSERVATION OF BARYONS

No examples have yet been found of hyperon production in which the whole mass has been created from kinetic energy. It appears that a hyperon must be built on a nucleus as basis. In the same way no reaction has been observed in which the whole mass of a hyperon has been transformed into kinetic energy or rest-mass energy of particles lighter than nucleons. This suggests that hyperons together with nucleons constitute a conserved class of particles which are referred to as baryons. We then have the new conservation rule: 'In any reaction the number of baryons must be conserved.'

#### ASSOCIATED PRODUCTION— THE 'STRANGENESS' QUANTUM NUMBER

It follows from the baryon conservation rule that a hyperon can be produced only in a collision between two particles if one at least is a nucleon. A further remarkable fact is that in all observed cases a hyperon is produced only in association with one or more  $\kappa$ -mesons. Thus we have the reactions

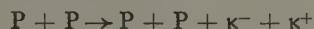
$$\begin{array}{l} \pi^- + P \rightarrow \Lambda^0 + \Theta^0 \\ \text{or} \quad P + P \rightarrow P + \kappa_\mu^+ + \Lambda^0 \\ \text{but never } \pi^- + P \rightarrow \Lambda^0 + \pi^0 \\ \text{nor} \quad N + P \rightarrow \Lambda^0 + P \end{array} \quad \left. \right\} \dots \quad (11)$$

Furthermore, it seems that, while a  $\kappa^+$ - or  $\kappa^-$ -meson can be produced singly in association with a hyperon, a  $\kappa^-$ -meson can be produced only in association with at least one other  $\kappa$ -meson in addition.

It has been shown by M. Gell-Mann [6],

following earlier work of A. Pais [7], that the available data can be ordered in terms of a selection rule. To each meson, nucleon, and hyperon is allocated a number which, as an indication of the ignorance it conceals, is known as the 'strangeness' quantum number. These assignments are listed in the last columns of tables I, II, and III. A reaction can be a fast one only if the algebraic sum of the strangeness quantum numbers on each side of the reaction equation is the same. By a fast reaction is meant one which takes place in a time of the order of  $10^{-23}$  sec. If the total strangeness changes by  $\pm 1$  the time will be very much longer—of the order of the lifetimes of the  $\kappa$ -mesons and hyperons (see tables II and III). The probability of the reaction is negligible if the total strangeness changes by more than 1.

This scheme fits all the known data. Thus, referring to reactions (11) and tables II and III we see that in each case the total strangeness is unchanged and they lead to relatively copious production. On the other hand, in reactions (12) there is a change of total strangeness and the reactions are negligible sources of hyperons. Again, with the assignment  $-1$  as the strangeness of  $\kappa^-$ , the reaction  $P + N \rightarrow P + \kappa^- + \Sigma^+$  involves a change of strangeness. To avoid this we must turn to reactions such as



which require much more conversion of kinetic energy into energy of rest-mass.

The decay processes listed in tables II and III, which do not involve production of neutrinos, all involve a change of  $\pm 1$  in total strangeness. It is because of this that they are so slow.

So far the physical significance of the strangeness quantum number remains obscure. It is encouraging, however, that such a wide variety of data on the production and decay processes of  $\kappa$ -mesons and hyperons can be ordered in this simple way. The rules also seem to determine correctly the nature of the reactions of  $\kappa$ -mesons with nucleons.

#### HYPERNUCLEI

An interesting discovery is that hyperons may replace nucleons in nuclei to produce so-called hypernuclei which decay, in times of the order of the hyperon lifetimes, to produce normal nuclei and  $\pi^-$ -mesons. Examples are hyperhelium nuclei, which include 2 protons, 1 neutron, and 1  $\Lambda^0$  hyperon. A specially interesting one is hyper  $H^4$ , consisting of 1 proton, 2 neutrons, and a  $\Lambda^0$

TABLE I

The fermions (apart from the hyperons, for which see table III) all have spin  $\frac{1}{2}$

Particle	Symbol	Charge (in units $e$ )	Mass (electron mass)	Decay products	Lifetime (seconds)	'Strangeness' quantum number
Neutrino . . .	$\nu$	o	o	Stable	—	—
Electron . . .	$e^-$	— i	i	Stable	—	—
Positron . . . (anti-electron)	$e^+$	+ i	i	Stable	—	—
$\mu$ -meson . . .	$\mu^-$	— i	207	$e^- + 2\nu$	$2 \cdot 2 \times 10^{-6}$	—
	$\mu^+$	+ i	207	$e^+ + 2\nu$	$2 \cdot 2 \times 10^{-6}$	—
Proton . . .	$P$	+ i	1836.6	Stable	—	o
Antiproton . . .	$P^-$	— i	1836.6	Stable	—	o
Neutron . . .	$N$	o	1839.0	$P + e^- + \nu$	770	o
Antineutron . . .	$N^*$	o	1839.0	$P^- + e^+ + \nu$ (Not yet observed)	?	o

TABLE II

The bosons all have spin o except the photon, which has spin 1

Particle	Symbol	Charge (in units $e$ )	Mass (electron mass)	Decay products	Lifetime (seconds)	'Strangeness' quantum number
Photon . . .	$\gamma$	o	o	Stable	—	—
$\pi$ -mesons . . .	$\pi^+$	i	273	$\mu^+ + \nu$	$2 \cdot 5 \times 10^{-8}$	o
	$\pi^0$	o	265	$2\nu$ or $2e^+ + 2e^-$	$\sim 5 \times 10^{-16}$	o
	$\pi^-$	— i	273	$\mu^- + \nu$	$2 \cdot 5 \times 10^{-8}$	o
K-mesons:						
Tauons (?) . . .	$\tau^+$	i	966	$2\pi^+ + \pi^-$ or $\pi^+ + 2\pi^0$	$10^{-8}$	i
	$\tau^-$	— i	966	$2\pi^- + \pi^+$	?	— i
	$K_{\mu 2}^+$	i	966	$\mu^+ + \nu$	$10^{-8}$	i
Thetons (?) . . .	$\theta^0$	o	966	$\pi^+ + \pi^-$	$1 \cdot 7 \times 10^{-10}$	$\pm i$
	$K_{\pi 2}^+(\theta^+?)$	i	966	$\pi^+ + \pi^0$	$3 \cdot 7 - 8 \cdot 5 \times 10^{-10}$	i
	$K_{\pi 2}^-(\theta^-?)$	— i	966	$\pi^- + \pi^0$	?	— i
	$K_{\mu 3}^+$	i	966	$\mu^+ + 2\nu$ (?)	?	i
	$K_{e 3}^+$	i	966	$e^+ + 2\nu$ (?)	?	i

TABLE III  
*The hyperons (fermions with mass greater than that of the proton)*

Particle	Charge (in units $e$ )	Mass (electron mass)	Decay products	Lifetime (seconds)	'Strangeness' quantum number
$\Lambda^0$	0	2181	$P + \pi^-$	$3.7 \times 10^{-10}$	- 1
$\Sigma^+$	1	2327	$\begin{cases} N + \pi^+ \\ P + \pi^0 \end{cases}$	$0.3 \times 10^{-10}$	- 1
$\Sigma^-$	- 1	?	$N + \pi^-$	$0.3 \times 10^{-10}$	- 1
$\Sigma^0$	0	?	$\Lambda^0 + \gamma$	?	- 1
$\Xi^-$	- 1	2577	?	?	- 2

hyperon. 'Normal'  $H^4$  is not stable, because the third neutron cannot occupy as low a level as the first two, an exclusion which does not apply if the neutron is replaced by a hyperon.

#### DISCOVERY OF THE ANTIPROTON

The existence of the antiproton was demonstrated a few months ago [3] by the following technique. The particles issuing from a copper target bombarded by the 6.2 GeV beam of protons in the Berkeley bevatron were analysed by a magnetic field so that the issuing beam had a definite momentum and was negatively charged. This beam consisted mainly of  $\pi^-$ -mesons moving with a velocity of 0.99 times that of light. Any antiprotons present would have the considerably lower velocity 0.78c.

Two scintillation counters were placed in the beam at 40 ft apart.  $\pi^-$ -mesons traversed this distance in  $4 \times 10^{-8}$  sec. By noting the time delay between coincidences on the two counters it is possible in principle to tell whether the activating particle is an antiproton or not. As there were at least 40 000 times as many  $\pi^-$ -mesons as antiprotons in the beam, it was necessary to eliminate

chance coincidences very thoroughly. This was done by inserting two Čerenkov counters in the beam; one, A, was operated only by particles with velocity 0.79c, and the other, B, was operated only by particles with velocity between 0.75c and 0.79c. In order that an antiproton should be recorded, the time delay on the original two counters had to be correct, and also Čerenkov counter B, but not A, operated as well. In the first experiment 250 of these events were recorded, very many more than could possibly be due to chance.

#### FUTURE PROSPECTS

The rapid development of technique, both in the scope of artificial acceleration and in methods of detection, is bound to provide much more extensive and precise data about the mesons, hyperons, and antiprotons. It may well be that most varieties of particle have already been discovered, but there may well exist others, whose lifetimes are so short as to defy detection by present methods. This applies particularly to neutral particles. It is not too optimistic to hope that, before long, some theoretical clarification of the relations between the particles will be made.

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# The Royal Society portraits

E. N. DA C. ANDRADE

The Royal Society has, in its long history, formed a considerable collection of portraits which is of general interest for both the eminence of many of the men they represent and the merit of many of the paintings. Owing to the way in which it has accrued, a number of characters not notable for great achievements in science, but nevertheless of interest, are included with figures of outstanding genius. The collection is here reviewed, the attribution of the well known portrait of Christopher Wren being among the questions considered.

The Royal Society from its early days has received gifts of portraits and today possesses a collection which is distinguished both by the outstanding genius of many of those depicted and by the mastery of many of the artists concerned. It is not always that the two are combined. The beautiful example of Hogarth's art in the Society's possession is a portrait of Martin Folkes, the antiquary, who was President from 1741 to 1752, but was a man of no great scientific distinction: in fact Stukeley records that under his presidency the meetings were 'a most elegant and agreeable entertainment for a contemplative person', which suggests no great scientific rigour. On the other hand, there are cases of men of great scientific eminence depicted by artists not conspicuous for their mastery, of which it would be ungracious to give examples.

On the whole, however, the standard of portraiture is high, and, among the older artists, men of the calibre of Lely, Kneller, Michael Dahl, Mary Beale, Reynolds, Thomas Lawrence, and Thomas Phillips are well represented. From 1880 to 1907 the Hon. John Collier, whose sober if uninspired veracity was well suited to academic portraiture and to the taste of the time, was supreme, having contributed seven portraits, including one of Charles Darwin (in copy) and a really excellent one of William Kingdom Clifford, a genius who, elected F.R.S. at the age of 28, died at 33.

Prominent among the early artists are Godfrey Kneller and Peter Lely, the leading English portraitists of their time—if we may call them English, for Kneller (originally Kniller) was born at Lübeck of good German stock and Lely was a Dutchman who came to England during the Civil War. To Lely is officially attributed the portrait of Viscount Brouncker, the first President of the Society as incorporated by the Charter of 1662. Brouncker was a considerable mathematician, whose work on continued fractions is re-

corded in the standard histories of mathematics. He continued as President until 1677, when he was succeeded by Sir Joseph Williamson, a statesman and diplomat who knew little of science, but took an interest in the affairs of the Society. Evelyn records of him that on 4th December, 'Being the first day of his taking the chaire, he gave us a magnificent supper'. He presented a fine portrait of himself, by Kneller, to the Society.

To Lely is somewhat doubtfully attributed the portrait of Charles II, Founder of the Society, which hangs over the President's chair. Contrary to the usual belief, the portrait did not come into the Society's possession at, or near, the time of the foundation. It belonged to the Marquis of Hastings, who died in 1826, and was acquired after his death. Another portrait attributed to Lely is that of Henry More, the Cambridge Platonist, elected Fellow in 1664 but never active in the scientific field. He was, however, a friend of many prominent Fellows, including Boyle and Newton.

Kneller is nominally responsible for more of the Society's portraits than any other single man. The best known of those that bear his name on the official list is that of Christopher Wren, who succeeded Joseph Williamson as President in 1680. Unfortunately it would seem that the portrait is not by Kneller at all, although in Elmes's 'Memoirs of the Life and Works of Sir Christopher Wren' (1823) it appears as the frontispiece, engraved 'after the Original Picture of Sir Godfrey Kneller's in the Council Chamber of the Royal Society'. In the 'Dictionary of National Biography' it is 'believed to be by Sir Peter Lely, though there seems some ground for attributing it to Sir Godfrey Kneller'. In the Royal Society printed catalogue of portraits dated 1860, compiled by C. R. Weld, who wrote a well known 'History of the Royal Society,' it is definitely set down to Lely, and as presented by Stephen Wren. Stephen Wren published in 1750, under the title

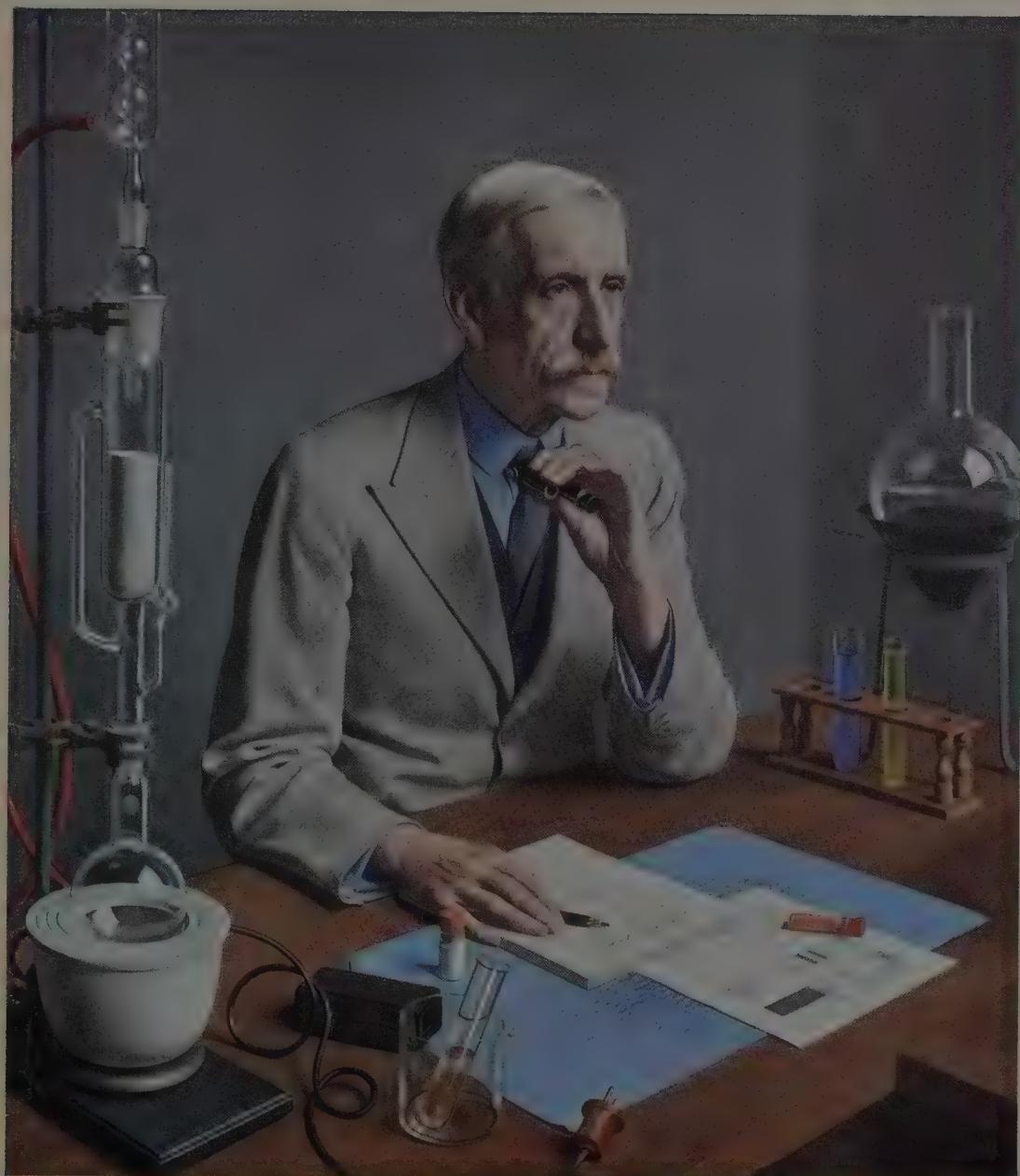
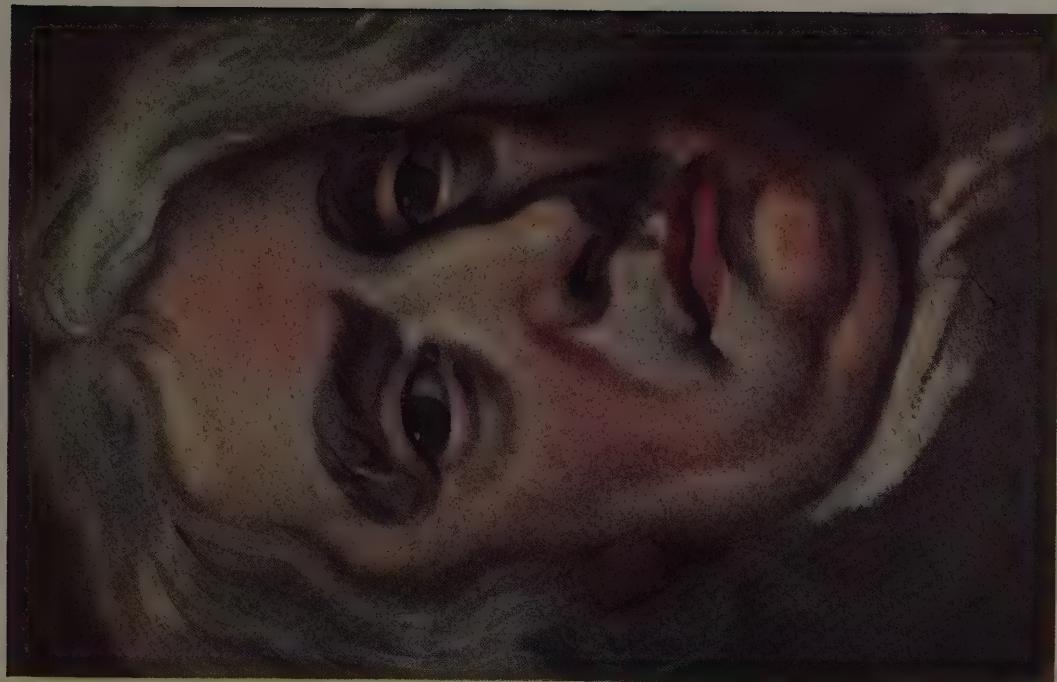


PLATE I.—*Sir Frederick Gowland Hopkins, President 1930-35. By Meredith Frampton.*

PLATE 3 - *Lord Brouncker, President 1662-77. By Sir Peter Lely.*PLATE 2 - *Sir Christopher Wren, President 1680-82. Probably by J.B. Closterman.*

PLATE 5 - *Sir Isaac Newton, President 1703-27. Study by J. Vanderbank.*PLATE 4 - *Sir Joseph Banks, President 1778-1820. By Thomas Phillips.*

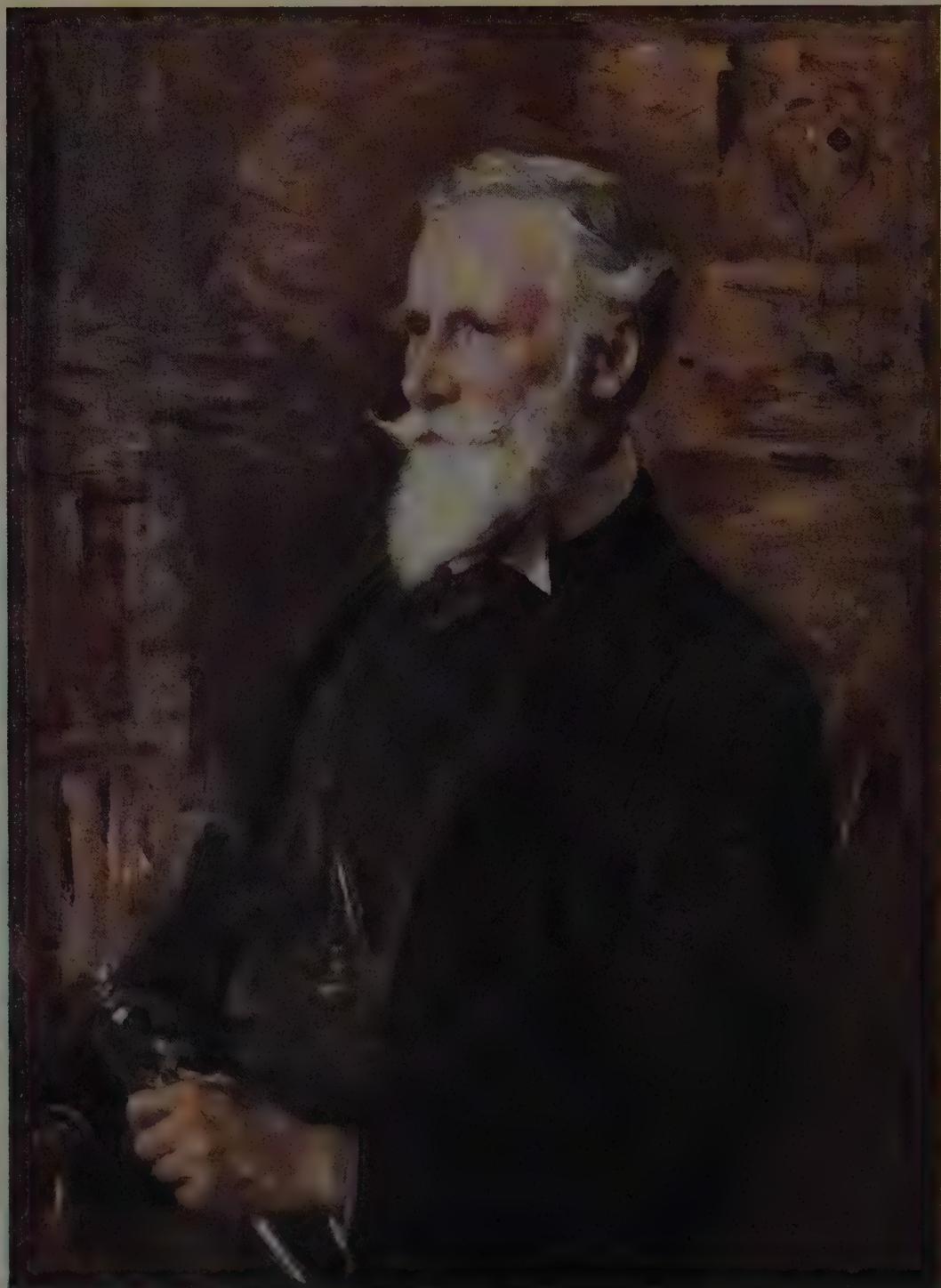


PLATE 6 - *Sir William Crookes, President 1913-15. By E. A. Walton.*

*Parentalia*, a history of the Wren family compiled by Christopher Wren, the son of Sir Christopher, and ought to have known; but in the book this portrait is not mentioned, and the attribution may not have been that of the donor. However, in a later, anonymous, edition, dated 1892, of the printed catalogue of portraits of 1892, the attribution is 'Sir P. Lely (? Sir G. Kneller)', while in the 1931 edition it is definitely set down as by Kneller. Yet in an edition of the Society's catalogue dated 1912 it is 'attributed to Michael Wright', a Scottish portrait painter who died in 1700.

Here are three attributions. However, as pointed out to me by Mr Oliver Millar, the portrait is almost certainly by J. B. Closterman, since an engraving from it by E. Kirkall, executed about 1730 and hence almost contemporary, so attributes it. Mr Millar suggests 1695 as the approximate date, later than a previous unsupported attribution of 1687. The date 1695 would make Wren's age at the time 63, which accords well with his features. The representation of St Paul's Cathedral in the background affords independent evidence on this point. The west towers are shown as planned at an early period, before they were raised on high pedestals with segmented arches, as first seen in an engraving of the design in 1702. The dome, which is shown nearly as executed, suggests a date not much before 1694, when the decision to proceed with the dome was taken. The design was still quite undetermined in 1690.<sup>1</sup> The Cathedral as shown offers, then, good reason for setting 1690–1702 as limiting dates.

A famous portrait, undoubtedly by Kneller, that emphasises, as does his Williamson, that outstanding scientific distinction was not in those days an indispensable qualification for President of the Royal Society, is that of Samuel Pepys, who reigned from 1684 to 1686 and put his *Imprimatur* on the manuscript of Newton's *Principia*, of which he undoubtedly could not have understood a word.

Between Wren and Pepys were two Presidents whose portraits are not in the possession of the Society, Sir John Hoskins, a lawyer, and Sir Cyril Wyche, politician and diplomat. Eight other Presidents (not counting Sir Robert Moray, President before the First Charter) are not represented, among whom are two whose absence must cause astonishment—George Biddell Airy, the great astronomer, who held office from 1871 to

1873, and Thomas Henry Huxley, 1883–85. After Huxley, all the Presidents answer the roll. Up to and including Gowland Hopkins, who held office from 1930 to 1935, it had long been the custom for the presidential portrait to be presented to the Society by subscribers; since that time the portrait has been commissioned by the Society.

After Pepys came five Presidents whose names, distinguished though they be, are little known for scientific accomplishment. Of two of them, Sir Robert Southwell and Lord Somers, there are Kneller portraits; of Charles Montagu, afterwards Earl of Halifax, Newton's friend and promoter, there is, strangely enough, no picture. Then, in 1703, the supreme Isaac Newton was elected to the Presidency, which he held to his death in 1727.

Of Newton there are three formal portraits in the possession of the Society. The earliest is by Charles Jervas, who was for a short time a pupil of Kneller's, painted in 1717, when Newton was seventy-four years old; the other two are by Vanderbank, one of 1725 and the other of 1726, and so painted not long before his death. The 1725 portrait was engraved by Vertue as a frontispiece to the third edition of the *Principia* (1726). There is a practically identical copy of this portrait at Trinity College, Cambridge.

All these portraits, then, represent Newton as an old and world-famous man, sedate, dignified, acclaimed, magisterial, with his work accomplished and his sway supreme. They have been frequently reproduced. It is to be regretted that the Society does not possess, even in copy, a version of the Kneller portrait in the possession of the Earl of Portsmouth, showing Newton at about the time when the *Principia* was written, an impressive delineation of a face of dominating intelligence and strange, remote, almost hostile, genius. Recently (1950) the Society purchased a study in oils on paper executed by J. Vanderbank. It is, naturally, less formal and so in many ways more interesting than the final portraits. Quite apart from the fact that it shows the great man without wig, it bears the impression of a more direct transcription of a normal expression. It is reproduced, for the first time, in Plate 5.

Newton's immediate successor was Hans Sloane, about whose portrait by Kneller there can be no controversy, for Sloane presented it in his lifetime, after he had given up the secretaryship and before he became President. He was followed by Martin Folkes, whose portrait by Hogarth has already been mentioned. Contemporary opinion is summarized in the epigram:

<sup>1</sup> I am indebted to Mr John Summerson, whose deep learning in matters pertaining to Wren's architecture is well known, for the facts here set down concerning the design.

'If e'er he chance to wake in Newton's chair  
He wonders how the devil he came there.'

After five presidents little known today, of whom three presented their portraits, as was the custom, comes the redoubtable Joseph Banks, on many grounds an outstanding figure. He was President for forty-two years, a period far longer than the reign of any other President, Isaac Newton coming next with twenty-four years. He had sailed with James Cook in the 'Endeavour' as naturalist, bearing all the expenses of his staff and equipment, as his fortune allowed him to do. His rule as President was forceful and autocratic, but munificent. He was very proud of being made a Knight of the Order of the Bath. The Society portrait by Thomas Phillips, one of several of Banks which he produced, expresses well his personality. It shows him in the President's chair, in front of him the inkstand that will be familiar to Fellows, evidently ruling, and adorned with the star and ribbon of his Order.

The portrait of his successor, W. H. Wollaston, who among many outstanding feats can claim the discovery of rhodium and palladium, is well known and has often been reproduced. It is one of two painted by J. Jackson; Thomas Lawrence also executed one. Even better known, perhaps, is the three-quarter length of handsome, fashionably dressed, self-confident Humphry Davy by Thomas Lawrence, looking the observer squarely in the face. A figure of quite a different kind is the amiable Duke of Sussex, whose election must, I think, have been the last to be the subject of a contested ballot among the Fellows—and a closely contested ballot, for the Duke obtained 119 votes and Sir John Herschel 111. The portrait of the Duke is a typically competent one by T. Phillips, showing him wearing his star and ribbon of the Order of the Garter and a benevolent expression. There is a different version of it at the Reform Club.

A beautifully painted portrait, showing the quiet and perceptive mastery of his style, is that which Orchardson executed of Lord Kelvin in his old age (about seventy-five), four years after his retirement from the Presidency. The portrait of Lord Rayleigh by Sir George Reid is remarkable for being wider than it is high, an admirable composition in which the sitter is at his study table.

Among the portraits of Presidents of the present century one of the most striking is that of William Crookes by E. A. Walton. As in so many cases, it shows the subject as an old man—about seventy-nine in this case, with his most famous work well past—but an extremely striking and alert old man,

grasping in his hand a Crookes tube of some kind. There is also in the Society's possession a very good bronze bust of Crookes, executed a few years earlier. It may be noted, incidentally, that while there is no portrait of Alfred Yarrow, Fellow and most generous benefactor, there is a bronze bust of him.

J. J. Thomson, Charles Sherrington, Rutherford, Gowland Hopkins, W. H. Bragg, Henry Dale, Robert Robinson, Lord Adrian are all represented by faithful portraits: that of Lord Adrian, whose term of office concluded last year, by A. R. Middleton Todd, a quiet but very faithful and understanding delineation, having just been suspended. In the portrait of Rutherford, which is a bold and successful representation of the great man in a characteristically informal pose and with a typical expression, scientific apparatus—that used for the identification of alpha particles as helium—is prominently introduced, an unusual feature in presidential portraits. But the most striking example of this is in the portrait of Gowland Hopkins by Meredith Frampton, where the subject, holding his little direct-vision spectroscope, is shown at work amid the typical tools of his craft. This picture is altogether in a lighter colour scheme than that of the general run of portraits and, as is bound to be the case with a highly individual piece of work, although generally admired has its critics among the Fellows. The writer is a whole-hearted approver, as he is of the very striking portrait of Robert Robinson by A. K. Lawrence, which when exhibited at the Royal Academy was one of the pictures of the year. This is in many ways a complete contrast with the Gowland Hopkins portrait, showing the subject in academic robes and more formal pose, if with a characteristic spread of fingers on the thigh. It is not, perhaps, the Robinson of the witty, incisive, casual conversation of his leisureed hour, but it is very much Robinson the President, presiding on some serious occasion.

The portraits are not, of course, restricted to the Presidents, nor even to what would today be considered men of science. That of Henry More has already been mentioned. Until recently all the portraits were presented, and it would clearly be hard to decline a gift, especially if the donor were a forceful or influential figure. This may well account for the presence of some of the less appropriate persons, such as Samuel Chandler, officially listed as 'Dissenting Theologian', the same description being applied to Richard Price, whose portrait also hangs.

Among the non-presidential portraits are, however, those of some of the most celebrated figures in the history of science, starting with Robert Boyle, of whom there are two good and well known representations, one by Kerseboom and the other by John Riley. Strangely enough, both came into the possession of the Society long after the great man's death: they were presented in, respectively, 1765 and 1876. Another Original Fellow and early hero of the Society is John Wilkins, excellently depicted by Mary Beale: a third Original Fellow is the great mathematician John Wallis, whose portrait, by Gerard Soest, was presented just after his death in 1703. John Flamsteed, the first Astronomer Royal, looks sourly from the wall, as well he may, considering what he had had to put up with by the time he reached the age of 66 at which he was painted by T. Gibson. Of his successor, Edmond Halley, there are two portraits, one, by Thomas Murray, showing him as a bland youngish man in his own hair, and the other, by Michael Dahl, showing him as a grim old man of eighty, with formal wig. It is interesting to compare the two. James Bradley, his successor as Astronomer Royal, is another famous figure, excellently portrayed by Jonathan Richardson. The portrait of Jesse Ramsden, the great astronomical instrument maker, whose name is known to all students of elementary physics by the Ramsden eyepiece, is one of the few that show instruments in detail, the background being the celebrated five foot vertical circle that he made for the Palermo observatory. Ramsden is depicted as in a fur coat, in allusion, it is said, to the fact that he had lately completed a commission for the Czar of Russia. It is further recorded that the sitter, a plain-spoken Yorkshireman, did not approve and said that he had never worn such a thing in his life.

The painter of Ramsden is Robert Home, the brother of Sir Everard Home, who presented the picture to the Royal Society. Robert Home likewise painted, and Sir Everard presented, the well known portrait of John Hunter, the surgeon, who had married Home's only sister, with his peculiar dog. Robert Home later went to India, where he acquired considerable wealth as court painter to the King of Oude. Sir Everard Home, the first President of the Royal College of Surgeons, was a prominent Fellow, a Copley medallist, nineteen times Croonian Lecturer (easily a record!), and author of 110 papers in the Philosophical Transactions, which is possibly another record. It is said that he borrowed, in these matters, exten-

sively from Hunter. His own portrait, by T. Phillips, he likewise presented to the Society.

To return to men of outstanding scientific fame, the portraits of Thomas Young and Charles Darwin are copies of well known works. That of Faraday is a vivacious representation of the great man at the height of his powers, by A. Blaikley. Less familiar are the features of Dalton and Joule, of whom the portraits in the Royal Society are by R. R. Faulkner and the Hon. John Collier respectively. There were portraits of both of these Manchester notables in the possession of the Manchester Literary and Philosophical Society, but they were lost when this Society's house was burnt down as a consequence of air attack on 23rd December 1940. The Joule seems to be the only painting of him now in existence. An impressive and interesting portrait is that of Benjamin Franklin by Joseph Wright (not the Joseph Wright whose dramatic 'Experiment with the Air-Pump' is now in the Tate Gallery, but an American-born artist, son of Patience Wright, who was well known as a modeller in wax). It would appear to be based on a painting by J. S. Duplessis, although this has been disputed.<sup>1</sup> The portrait by G. F. Watts of the chemist Thomas Graham gives him, perhaps, rather more of the Sir Galahad look than is indicated by that in the National Portrait Gallery.

The likeness of the aged, aged Fontenelle, elected a Foreign Member at the age of seventy-five, who, but for a few days, lived to be a hundred, looks sadly from the wall. It is a copy of a picture by Voiriot which would appear to have been painted well after his election. The mathematician Brook Taylor, known to students for 'Taylor's series', who, on the other hand, died young, appears in the Royal Society portrait, the only one known, as a bright and rosy face framed in a very high wig. Another great eighteenth-century mathematician of whom there is an arresting portrait is De Moivre, by Joseph Highmore. After studying this remarkable face it is not difficult to believe both that Newton in later life would refer questioners on difficult points in the *Principia* to De Moivre and that De Moivre knew the works of Molière and Rabelais almost by heart. About his love for the latter he must have been able to keep discreetly silent when necessary, for he was an intimate friend of the puritanical and serious Newton. This devotion to Rabelais is a trait that

<sup>1</sup> See C. H. Hart. 'Joseph Wright's Portrait of Franklin belonging to the Royal Society, London.' *Pennsylvania Magazine of History and Biography*. July 1908.

he shared with Benjamin Franklin. Malpighi and Meldola; John Herschel and Huggins; Lord Rosse, father of Charles Parsons of turbine fame (of whom the Society has no portrait), and Rumford are other figures who might detain us, were there time.

Among the portraits are further those of a number of outstanding investigators who were not Fellows of the Society. Some of these pioneers lived before the Society was founded, such men as Tycho Brahe, Copernicus, Descartes, Galileo, and William Harvey. The Copernicus, Descartes, and Galileo are acknowledged copies: the Tycho Brahe, presented by a Fellow, James Hodgson, in 1732, is ascribed to the celebrated portraitist M. J. Mierevelt, of whom it is written, without exaggeration, 'but comparatively few of the two thousand or more portraits that bear his name are wholly his own handiwork'. There is, not surprisingly, a portrait of Francis Bacon, for at the time of the inception of the Society he was so much considered a contributor to the foundation that his representation, with the words *Artium Instaurator* beneath it, is the most prominent figure in the frontispiece engraved by Wenceslaus Hollar for Sprat's 'History of the Royal-Society' (1667). It was presented by Martin Folkes in 1754: he was, no doubt, in sympathy with this early tradition. A portrait of Thomas Howard, Earl of Arundel, copied from a Van Dyck, was presented by Isaac Newton. The Earl died before the Society was founded, but the family was kindly disposed to the new body. For some years in its early days the Society met at Arundel House, and the building of a house for the Society was contemplated on a portion of ground offered by Mr Henry Howard, who in 1666 presented to the Society the valuable library known as the 'Arundel Collection'. Incidentally, most of these books, not of immediate scientific interest, were sold in 1924, the proceeds, some £6500, forming the Arundel fund, the income from which helps substantially to maintain the library.

The Arundel family may, then, well claim a place among the portraits. What, however, can be urged to justify space on the Society's walls for the portrait of the Scottish historian George Buchanan (1506–82) is not very clear, except that it was presented by Thomas Povey, a socially prominent Fellow, who frequently appears in the diaries of Pepys and Evelyn. Henry Spelman (1561–1641) is another historian whose presence is still harder to explain, for not even the donor is known. The

painting is attributed to D. Mytens. The portrait of J. C. Sturm, the author of the popular *Collegium Experimentale*, who died in 1703, was presented by Theodore Haak in 1683. Theodore Haak, although a man of no scientific achievement, was an Original Fellow and took an active part in the proceedings that led to the foundation of the Society. His own portrait, an excellent piece of work, hangs on the wall. It is strange, then, that while he took sufficient interest in Sturm to present his portrait during his lifetime he never arranged his election as Fellow. It was not very difficult to enter the Fellowship in those days.

But the strangest of the non-Fellows to be present is, perhaps, Thomas Hobbes. In the years preceding the foundation of the Society he had had violent disputes with Seth Ward and John Wallis, who had exposed the absurdity of his mathematical lucubrations. John Wallis, already mentioned, was one of the ablest mathematicians of his day and took a very prominent part in the foundation of the Society, which Hobbes was not invited to join. In view of his scientific pretensions he much resented this exclusion: he attacked Robert Boyle and continued his futile controversies with Wallis until his death in 1679. He was, then, as far as science is concerned, a conceited and wrong-headed eccentric, an enemy to some of the chief promoters of the Society, and a bitter opponent of much pioneering scientific work of his time. Yet there hang prominently in the home of the Society two excellent portraits of him, one, attributed to J. B. Caspers, presented during his lifetime by John Aubrey, the author of the 'Brief Lives', a close friend of his, and a second, bequeathed by a non-Fellow of the Society in 1717, showing him as a much younger man. It is set down as from the brush of William Dobson, the doyen of English portrait painters, but is probably not by him. Aubrey says 'Twas pitty that Mr. Hobbs had not began the study of the Mathematics sooner, els he would not have layn so open. But one may say of him, as one says of Jos. Scaliger, that where he erres, he erres so ingeniously, that one had rather erre with him than hitt the marke with Clavius.' Truly the whirligig of time brings in his revenges. It is, perhaps, fitting that this account should close with this outstanding example of the generosity and toleration of the Royal Society.

I am much indebted to Mr C. K. Adams, Director of the National Portrait Gallery, London, who kindly read through a draft of my article and gave me valuable information.

# New kinds of macromolecules

C. E. H. BAWN

The past twenty-five years has seen immense progress in our understanding of the nature of macromolecules and in the development of general methods of synthesis. Recent research has led to the development of new synthetic methods which yield macromolecules of types not previously known and possessing combinations of properties indicating a wide range of practical applications for them. These developments have also very great theoretical significance.

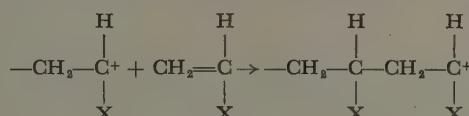
High polymers are composed of chemical molecules very much larger in size than those occurring in the more familiar compounds of chemistry. The acceptance of this hypothesis some twenty-five years ago had a profound influence on the trend of research and was without doubt the major factor responsible for the immense progress in the study of macromolecules which has occurred in recent years. In spite of these developments the structures of the macromolecules which may be synthesized by present-day methods are still relatively simple compared with those found in naturally occurring high polymers like the proteins or polysaccharides. Recently, significant progress has been made in the synthesis of new kinds of macromolecules, and in this article some of this work will be briefly reviewed.

The formation of a macromolecule from its basic constituents depends on the setting up of a stepwise repetitive reaction in which the simple units are successively added to a growing molecule. Substances which undergo this kind of reaction fall broadly into two classes. The first comprises those in which the monomer units combine together in the presence of suitable catalysts without the formation of other products; this is known as addition polymerization. This process is largely confined to certain classes of unsaturated molecules, and polymer formation occurs by either a free radical or ionic chain mechanism. In the former case the chain growth process may be illustrated by the example shown below, in which  $R^*$  is a free radical used as initiator.

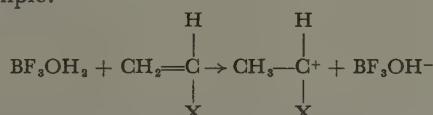
If the chains are long the formula of the polymer is an integral number of times the molecular

formula of the monomer. Well known members of this class are polyethylene ( $X=H$ ), polyvinyl chloride ( $X=Cl$ ), and polystyrene ( $X=C_6H_5$ ).

Certain vinyl monomers may be polymerized by very small amounts of catalysts of the type used in Friedel-Crafts reactions. Effective catalysts include  $SnCl_4$ ,  $AlCl_3$ ,  $BF_3$ ,  $TiCl_4$ , and  $H_2SO_4$ , and by analogy with polar mechanisms of other reactions these polymerizations involve carbonium ions, the propagating step consisting of the addition of a monomer to a carbonium ion:

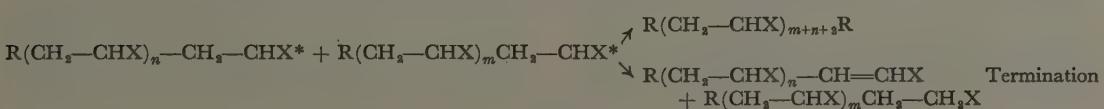
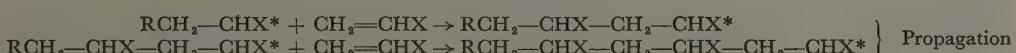


The initiating reaction, which forms the carbonium ion, consists of the transfer of a proton or other cation to the monomer, and it is widely accepted that the catalyst is not effective without an added co-catalyst such as water,  $HCl$ , etc., for example:



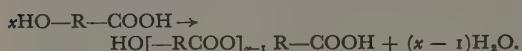
*Isobutylene*, styrene, methyl styrene, dienes, vinyl alky-ethers, and cyclo-ethers are typical monomers readily converted to high-molecular polymers by the above catalyst types.

Monomers with electronegative substituents may polymerize by an analogous anionic mechanism in the presence of reagents capable of forming carbonions. Thus, sodium or potassium amide

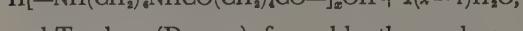
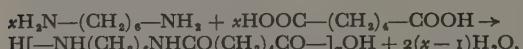


in liquid ammonia is particularly effective with acrylonitrile and methyl methacrylate, and metallic sodium with butadiene and isoprene.

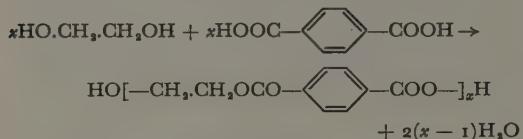
The second class consists of polymers which are formed from monomers bearing two or more functional groups which condense together, in successive stages, usually with the elimination of a small molecule ( $\text{H}_2\text{O}$ ,  $\text{CO}_2$ ,  $\text{NH}_3$ , etc.):



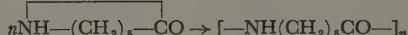
Important examples of this class are nylon 66, formed by the condensation of adipic acid with hexamethylene diamine:



and Terylene (Dacron), formed by the condensation of ethylene glycol with terephthalic acid:



Polymer formation by an intermolecular condensation of bifunctional monomers may also be obtained by the addition polymerization of certain cyclic compounds, e.g. lactams, lactones, ethylene oxide, etc.:



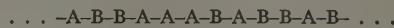
The pattern of the polymer-forming reaction is thus simple, and in the resulting polymeric structure the structural units are connected one to another by chemical bonds in a linear sequence. It is the size and structural arrangement of the high polymers which endow them with their unique properties of high viscosity, tensile strength, toughness, elasticity, and deformability, and which distinguishes them from the more familiar simple molecules.

The nature of the polymer—whether it is rubber-like, plastic, or fibrous—is determined also by the detailed shape and chemical structure of the macromolecules. These factors determine both the regularity of the packing of the molecules and the strength of the forces holding the molecules together in the solid. Strong intermolecular action causes the long linear chains to pack together in an orderly array as in a crystal, and the polymer exhibits fibre-forming characteristics. At the other extreme, the inter-chain forces may be so weak that the chains can take advantage of their in-

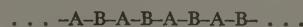
herent property of flexibility and by virtue of free rotational movement around the connecting bonds can assume a coiled-up configuration. Stretching of the solid now favours chain alignment or crystallization, but on release of tension the chains return to the coiled-up state. This is the molecular picture of elasticity, and materials composed of molecules having these properties show rubbery characteristics. A gradual transition from fibrous to rubbery properties may be observed in a polymer when the ordered arrangement and linear symmetry of the molecule is destroyed by, for example, the introduction of bulky side groups on the main chain structure. In nylon the strong hydrogen bonding between the chains, which is responsible for the properties of this fibre, may be progressively reduced by replacement of the hydrogen atoms of the  $-\text{CO}-\text{HN}-$  groups by methyl ( $\text{CH}_3$ ) groups, and there occurs at the same time a steady transition in properties from a crystalline fibre, through the rubbery state, to a viscous liquid of low melting point.

#### COPOLYMERS

The physical and mechanical properties of the polymer may also be materially modified by introducing a second type of monomer into the backbone structure. This may be accomplished by polymerizing a mixture consisting of two or more unsaturated monomers. The polymer formed is built up of units from each of the monomers and the  $1:1$  copolymer formed of the monomeric units A and B might be represented as follows:



The structure contains the units A and B arranged in a random manner. The composition of the copolymer and the relative distribution of the units along the chain is determined by the relative reactivities of the monomers. Certain pairs of monomers, for example allyl acetate and maleic anhydride, provide an exception to the above in that they react together to form the structure



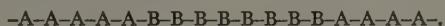
in which the groups A and B alternate regularly. Apart from such special cases the methods of synthesis do not permit control of the exact arrangement of the monomer units, and only the average composition can be accurately specified.

Copolymerization destroys the regularity and symmetry of the main unit, and in a copolymer composed of constituents which differ geometrically, in polarity, or in other properties which determine intermolecular action, the possibility

of the formation of ordered crystalline arrangements is considerably reduced. If one of the constituents is present in only small amounts in the copolymer, then sufficient sequences of units of one of the components may be present to maintain some degree of crystallinity. At the same time the effect of the addition of the second component is to reduce the melting point of the polymer, just as the melting point of a pure substance is lowered by a small addition of an impurity. Copolymerization therefore provides a powerful means of modifying and increasing the range of properties, and has been used extensively for the synthesis of polymers having to meet particular requirements. When copolymerized with acrylonitrile, polyvinyl chloride, which has a relatively low softening point, gives a fibre of higher softening point and a greater range of solubility. In contrast, vinylidene chloride is used as a copolymer with 15 per cent vinyl chloride added in order to lower its softening point and to reduce crystallinity. Similarly, the melting point of polyethylene terephthalate is lowered and its crystallinity decreased by copolymerization with aliphatic dibasic acids.

#### GRAFT AND BLOCK COPOLYMERS

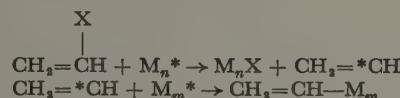
It is clear that in addition to the random and alternating distribution of the structural units in a copolymer formed from two components A and B, other types of structure are possible. The most evident of these is that in which the units A and B are suitably ordered into long segments of uniform composition, namely



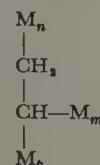
Copolymers of this type are known as block copolymers. A further modification of the copolymer structure arises when the second monomer is not incorporated in the main linear chain of A's but is attached to it by long or short side branches. This structure differs from any previously discussed in being non-linear, and many variants of the arrangement can be imagined. Thus the main backbone chain may itself be a copolymer of A and B and the graft formed with a third monomer, C, or the branch may be non-linear because of sub-branches. The properties of block and graft copolymers will be very different from linear copolymers made from the same pair of monomers, and the recent discovery of methods of synthesis of these kinds of structure is very important.

In the polymerization of a single vinyl monomer it is observed in some instances that the chain

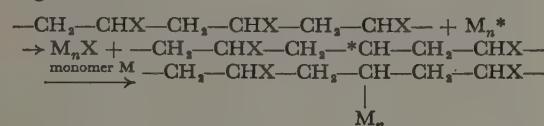
structure is occasionally interrupted by the formation of a branch. This is brought about by a chain transfer reaction during the polymerization, and involves the abstraction of an atom from the monomer molecule by the growing polymer radical  $M_n^*$ , for example:



The terminal unsaturated unit thus formed may be incorporated in the chain of another polymer molecule, when a branch results:



In a similar way reaction between a growing polymer-free radical  $M_n^*$  and a preformed polymer molecule may lead to a branch in the following manner:



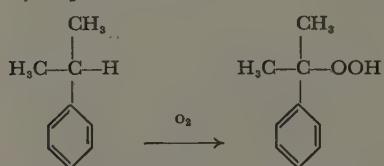
Branching in simple vinyl polymerization is not very common, and with one or two exceptions is not important so far as polymer formation and properties are concerned. Polyethylene (polythene), made commercially by polymerization of ethylene at high pressures and at temperature above 200° C, has been shown to possess one branch for each 20–100 carbon atoms in the main chain. These branches appear to be short, although occasionally a long branch occurs. The extent of branching depends on the conditions of polymerization and is less the lower the temperature of the reaction. Branching in polyethylene is of technological importance, since it causes a considerable modification of the properties of the polymer. The melting point of commercial (branched) polythene is about 112° C compared with 135° C for the linear polymethylene ( $(\text{CH}_2)_n$ ); the latter is considerably more crystalline.

The above concept of chain transfer in polymerization has recently been used in the synthesis of graft copolymers. If a polymer of one kind is dissolved in the monomer of another, which is then polymerized, chain transfer may occur between the growing chains and the already

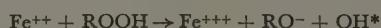
formed polymer chains. This produces a long-chain graft of one type of unit on the backbone of the polymer chain, and by the use of this method vinyl acetate, vinyl chloride, and styrene have been grafted on to polymethylmethacrylate and other polymers; methylacrylate grafted on to polystyrene; and styrene on to polystyrene [1]. When vinyl monomers are polymerized in the presence of rubber (polyisoprene) under suitable conditions some of the polymeric chains become attached to rubber molecules as a graft [2]. The product contains free rubber, together with a varying amount of free polymer formed concomitantly with the graft copolymer. In this way the properties of natural rubber can be widely modified. Some of the modified materials have unusual solubility characteristics, arising from the different behaviour towards solvents of the polymer and the rubber components of the molecule. Graft copolymers of styrene and methylmethacrylate with rubber can be readily compounded and cured to give light-coloured articles of good tensile strength, and with outstanding flex-cracking and fatigue resistance.

One of the difficulties in the use of the transfer method of grafting is that the branching on the chain occurs in a random manner, and the exact number and length of the branches cannot be controlled. Further, the homopolymer is formed together with the graft copolymer.

Another interesting method of making graft copolymers makes use of the ease with which certain hydrocarbon groupings can be oxidized to a hydroperoxide by air. Thus *isopropyl* benzene is readily oxidized by oxygen to the corresponding hydroperoxide:



Peroxides of this type are well known and are extensively used to initiate free radical polymerization:

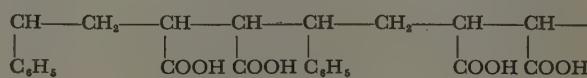


These facts have been applied by H. Mark and his collaborators [3] to polystyrene. On oxidation, a hydrocarbon polymer such as polystyrene, or polystyrene alkylated with *isopropyl* groups, behaves in an analogous way and gives rise to a random distribution of hydroperoxide groups along the polymer chain. In the presence of  $\text{Fe}^{++}$

or other suitable redox activator, reaction of the above type occurs with the formation of radical centres on the chain only; when this reaction is carried on in the presence of another monomer, graft copolymers are formed. The graft copolymers of vinyl derivatives and acrylic esters so formed on the hydrocarbon backbone show extremely interesting properties. Vinyl alcohol branches, which may be readily formed by the hydrolysis of vinyl acetate branches, are soluble in water and are fully extended, whereas the polystyrene backbone, being insoluble, becomes highly coiled, although it is prevented from precipitating by the 'soluble' branches. When added to benzene this copolymer shows the reverse effect, and the vinyl alcohol branches are insoluble. If water is now added to this solution it is absorbed into the vinyl alcohol part of the polymer; similarly benzene can be brought into solution by water suspensions of the polymer. Suspensions of these copolymers are stable, and may have important uses as detergents, in emulsion paints, or for the surface treatment of fibres.

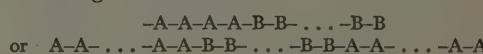
Alternative photochemical methods have been developed by H. W. Melville [4] and R. G. W. Norrish [5], using brominated polystyrene and polymethylvinyl ketone respectively. On photolysis, polymeric radicals formed by dissociation of the C—Br bond or the ketone grouping initiate polymerization of the added monomer.

Grafting on a preformed copolymer bearing functional groups may be carried out by a condensation reaction with a mono-functional unit. Thus, the condensation of the carboxyl group of the 1:1 copolymer of maleic acid and styrene—



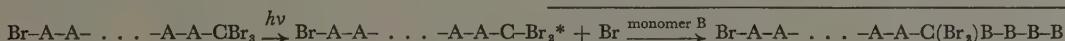
—with primary and secondary alcohols overcomes the difficulty of isolation of the graft copolymer; in this way the effect of length of side chain from C<sub>2</sub> to C<sub>23</sub>, and that of the degree of substitution of the carboxyl groups on the properties of the graft copolymer, have been measured [6].

The simplest and most direct method of synthesis of block copolymers is the direct scission of a polymer molecule  $A_n$  in the presence of a second monomer B. The scission gives a polymeric free radical which initiates the polymerization of the monomer B to form a product having one of the following structures:



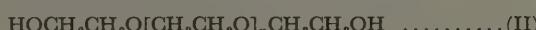
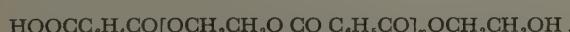
It has been claimed that any method for producing rapid shear—such as ultrasonic absorption, cold milling or mechanical mastication, high-speed extrusion, or rapid shaking—will cause the break-up of polymeric molecules into radical fragments. The most successful application of this method has been the synthesis of block copolymers of rubber with neoprene, synthetic rubber GR-S, acrylonitrile rubber, and with certain vinyl derivatives, by cold mastication of a mixture of two rubbers or a rubber with a vinyl monomer [7].

Other methods of synthesis depend on growing one polymer to an appreciable length, but still retaining a free radical end, before bringing it in contact with a foreign monomer. In one method of doing this the polymerization of one monomer is initiated photochemically at some point in a capillary through which it is streaming before passing into a vessel containing the second monomer. If the time of flow between illumination and exit is shorter than the average lifetime of the polymer radical the active species will initiate polymerization in the second monomer. Block copolymers of butyl acrylate and styrene have been made in this way [8]. An alternative method involves the preparation of a polymer with end groups which can be dissociated into free radicals on illumination; for example, the photolysis in a second monomer (B) of a polymer A having  $\text{CBr}_3$  terminal groups initiates the polymerization of the former. Block copolymers of styrene and methylmethacrylate have been so prepared [9]:



These methods produce the block copolymer in the presence of the two possible straight-chain copolymers, and consequently difficulties of separation arise. Also, the methods suffer from the disadvantage that only two blocks, one of each monomer or two of one and one of the other, are incorporated in the chain.

A more general method is that of linking together preformed polymers bearing functional end groups ( $-\text{COOH}$ ,  $-\text{OH}$ ,  $-\text{NH}_2$ ) by polycondensation. The most complete study of this type is the work of D. Coleman [10] on the preparation of block copolymers of polyethylene terephthalate (Terylene, Dacron) (I) with polyethylene oxide (Carbowax) (II),

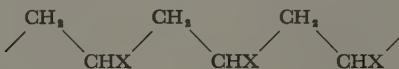


widespread in the field of proteins. Studies of the molecular constitution of silk fibroin indicate that the molecule contains two lengthy segments (about 170 Å long) which in contrast to the rest of the molecule carry bulky side chains which prevent their entry into the crystalline regions of the fibre. It has been suggested that the molecule may be represented as —C—A—C—A—C, where C represents readily crystallizable portions of the chain and A segments or blocks which constitute the non-crystallizing components.

#### ORIENTATED POLYMERS

A typically crystalline polymer is one in which the chemical and geometric structure is regular and there is no stereochemical irregularity. On the other hand, in non-crystalline polymers or copolymers

there is either chemical or geometric irregularity or both. In vinyl polymers  $(\text{CH}_2-\text{CHX})_n$  in which the structural unit bears a single substituent X, chemical and structural investigations have shown that the common and preferred structure of the polymer chain is that in which the substituent X is attached to alternate carbon atoms in a head-to-tail arrangement:



Although each alternate carbon atom in the chain is a centre of asymmetry, the *d* and *l* forms would be expected to occur at random along the chain. Experimental results support this view, and numerous attempts which have been made to resolve polymer molecules of this type have been unsuccessful. This stereochemical irregularity in the chain is the cause of the infrequency of the occurrence of crystallization in polymers in which the substituent X is large.

If the side group were regularly placed all on one side or successively in *d* and *l* configuration along the chain, a regular stereochemical pattern would result.

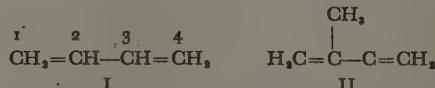
Recently, orientated polymers of this kind have been synthesized. G. Natta [12] has described the preparation of crystalline polypropylene, poly- $\alpha$ -butene, and polystyrene, and has suggested on the basis of X-ray diffraction evidence that these molecules are 'isotactic' and that in any one polymer chain, or at least in that forming part of a crystalline region, the substituent groups are identically placed, either all in the left-hand or all in the right-hand positions. These polymers were synthesized by a new type of catalyst which is believed to act heterogeneously and which directs the successive addition of monomer units to the growing chain in such a manner that long sequences of asymmetric carbon atoms having the same steric configuration are produced. The process is initiated, and probably occurs, at the catalyst surface, the growth reaction occurring by an ionic and not a free radical process. In all cases the isotactic polymer is formed together with the amorphous polymer, but these two forms may be separated by solvent fractionation. It has been claimed that certain specific catalysts give a 95 per cent yield of isotactic polymer with propylene. The use of these new catalysts has enabled the  $\alpha$ -olefins to be polymerized to high molecular weight solids for the first time. Thus propylene may be polymerized at low pressures to give a

crystalline polymer having fusion point 158–170°C and with good fibre-forming properties. Polystyrene, when normally prepared by free radical or cationic polymerization in the bulk or in solution, is a non-crystalline polymer with a heat distortion point of about 80°C. High molecular weight isotactic polystyrene is crystalline and fuses above 200°C. The solubility properties of the two polymer types are markedly changeable. Thus amorphous polystyrene having a molecular weight of one million is soluble in methyl ethyl ketone, whereas a crystalline polymer of the same molecular weight is insoluble. The mechanical properties of the polymer are drastically modified.

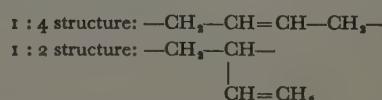
These interesting developments arose from the discovery of the so-called low-pressure ethylene polymerization process by K. Ziegler [13]. He showed that, using a catalyst formed by the interaction of aluminium triethyl, or other metallic alkyls, and certain metallic halides, such as titanium tetrachloride, suspended in a hydrocarbon, ethylene polymerized readily at ordinary pressures and temperatures to give a relatively unbranched polyethylene of high molecular weight. The new polyethylene has properties different from that of the material now in common use in that it has a much higher melting point, higher density, and greater crystallinity. In a sense, the low-pressure polyethylene can be regarded as an example of a polymer with a completely orientated structure, and the catalysts used in the preparation of the orientated hydrocarbon polymers described in the previous paragraph are of the same general type.

#### DIENE POLYMERIZATION

Normally the polymerization of 1 : 3 dienes such as butadiene (I) or isoprene (II)

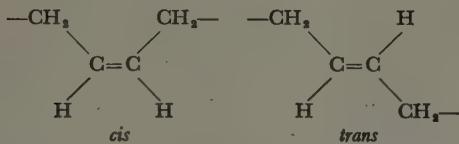


leads to the formation of polymers having various structures and configurations according to whether addition occurs in the 1 : 4 or the 1 : 2 position:

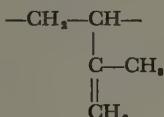


and in the polymerization of butadiene initiated by a free radical both types of addition occur, forming a structure which is very complicated.

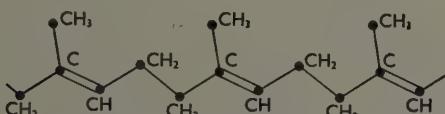
Also the 1 : 4 unit may occur either as a *cis* or *trans* isomer:



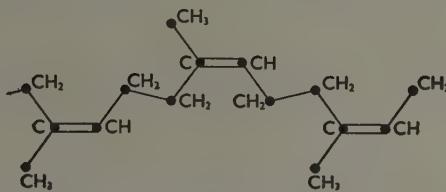
and the 1 : 2 units possess an asymmetric carbon atom which may give either *d* or *l* forms, as with the mono-substituted vinyl polymers. With the mono-substituted diene—isoprene—a further possibility of 3 : 4 structural chain units arises:



in addition to 1 : 2 and 1 : 4 unions. Structural studies of polyisoprenes prepared synthetically, using free radical initiation, shows units of all the above types to be present in the molecule. Natural rubbers which are polymers of isoprene, on the other hand, conform to a regular structure in which only one type of structural arrangement is present in the chain. Thus Hevea rubber has a *cis* 1 : 4 structure and gutta-percha (balata) a *trans* 1 : 4 structure.



Structural unit of extended rubber chain (*trans*)



Structural unit of extended rubber chain (*cis*)

Highly significant examples of directed polymerizations have recently been observed with the dienes. Starting with isoprene, several methods have been announced for its polymerization to a *cis*-polyisoprene almost indistinguishable from natural tree-grown rubber. For the first time it appears that the method of the synthesis of rubber in nature has been closely approached. One of these processes uses a dispersion of 0.1 part of lithium metal for 100 parts of isoprene as catalyst [14], and other processes use catalysts of the Ziegler type [14].

Using selective heterogeneous catalysts Natta [12] has prepared polymers of butadiene in which polymerization occurred exclusively in either the 1 : 2 position or 1 : 4 *trans* linking. He has also synthesized a polymer with 1 : 4 *cis* linkings predominating. The 1 : 2 polybutadiene gives orientated fibres with properties similar to those of the isotactic polymers. Structure studies have shown that, unlike the isotactic polymers, the asymmetric carbons are substituted alternatively on the left and the right. These developments have opened a new chapter in the stereochemistry of the polymer molecule, which from both the theoretical and practical points of view is of immense significance.

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# Some aspects of luminescence

G. F. J. GARLICK

Luminescence is of great theoretical and practical importance—its applications include the cathode-ray tubes of television receivers and the fluorescent lamp—and has in consequence been very closely studied in recent years. Although there is as yet no unifying theory which satisfactorily covers all manifestations of the phenomenon, the energy-transfer processes, to which particular attention is paid in this article, provide a common link between them all.

The emission of visible light from a body on suitable excitation, e.g. by ultraviolet radiation or by cathode-ray bombardment, when the temperature of the body is well below that at which such emission would occur thermally, is known as luminescence [1-3]. The term is a generic one and covers a number of subsidiary phenomena. For example, it is convenient to refer to the emission during excitation as fluorescence and that persisting after cutting off the excitation as phosphorescence, or more simply afterglow. The latter is due to the slow release of energy stored, during excitation, in the form of excited electrons trapped in metastable states of the system. Afterglow of more than a millisecond duration is usually found only in solids, though there are some exceptions, such as the airglow in the night sky. In this article we are concerned with solid materials. When these are synthesized in the laboratory and show luminescence they are generally referred to as 'phosphors'. When heated in the dark after excitation some phosphors show one or more bursts of luminescence as the temperature rises. This phenomenon is known as thermoluminescence, or thermal glow. It is due to the thermal activation of electrons from metastable states. The quantitative measurement of its variation with temperature for a uniform rate of warming provides a very powerful means of studying the metastable states in phosphors, and was developed for this purpose in the writer's laboratory by Randall and Wilkins (see [3]).

When luminescence is produced by a particular form of excitation the term is given a suitable prefix, e.g. radioluminescence due to bombardment by nuclear particles; cathodoluminescence produced by a cathode-ray tube beam; and so on.

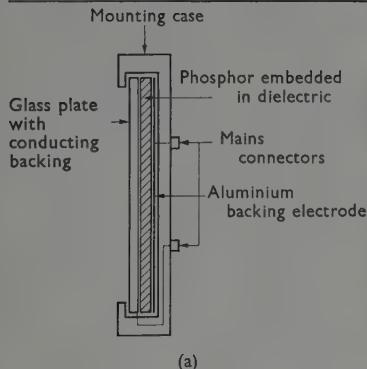
The applications of luminescence in such devices as the fluorescent lamp and the television cathode-ray tube screen are well known today [1-3]. Perhaps less well known are its applications in X-ray radiography, particularly in the recently

developed image-intensifier tube and in the detection of nuclear radiation by the scintillation counter [4]. The simplest form of luminescent source is the electroluminescent lamp. The structure of this is shown schematically in figure 1(a); figure 1(b) shows a photograph taken by the light of such a lamp. In such a lamp the luminescent material or phosphor is embedded in a transparent dielectric between two electrodes, one transparent, to which the a.c. mains voltage is applied. The efficiency is low, as will be shown later, and hopes of an improvement are at present slender.

Besides being of interest in such direct applications, luminescence is a concomitant of phenomena in solid-state physics which are turned to practical account; examples are the photographic process in silver halides at low temperatures [5], and charge-carrier injection in the crystal triode valve, or transistor. It occurs during certain chemical reactions (chemiluminescence); such reactions are of particular interest in living organisms (bioluminescence). In the present article we shall be concerned with an important process underlying all these phenomena and their applications, namely the transfer of energy—and particularly the efficiency of transfer—through a crystal or large molecule from the time of its absorption to its re-emission as luminescence. The inorganic phosphors are considered first, with particular reference to their performance in such devices as the fluorescent lamp and the cathode-ray tube.

## ENERGY TRANSPORT IN INORGANIC CRYSTALLINE PHOSPHORS [1, 3]

There are two main categories of inorganic phosphors on which interest is now centred: those in which luminescence is accompanied by photoconductivity—i.e. excitation produces free-charge carriers in the phosphor crystals—and those in which transport of energy in the crystals is an essential part of the luminescence process but takes place without the movement of charge.



(a)



(b)

FIGURE 1 - (a) Schematic diagram of an electroluminescent lamp. (b) Photograph of lamp by its own emission. (Exposure time  $\sim 1$  min. on rapid process plate.)

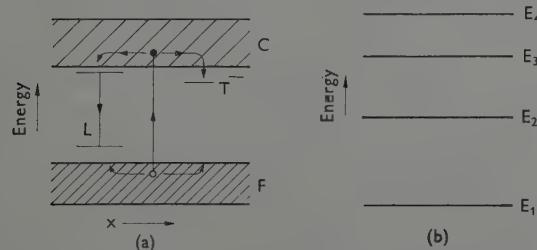
### (a) Photoconducting phosphors

Photoconducting phosphors, such as zinc and zinc cadmium sulphides, are the usual screen materials for television cathode-ray tubes. Their ultimate efficiency depends on the return, without loss, of the electrons liberated in the crystals by the primary excitation to specific centres where luminescence emission can take place. These centres are produced by including suitable impurities during the preparation of the phosphor. To explain the functioning of such phosphors one must examine the energy states for electrons in the crystals. These are shown in figure 2(a), the energy being plotted against a directional co-ordinate in the crystal. The possible energies for electrons in the host crystal are restricted by quantum laws, but fall into bands of allowed values separated by zones of forbidden values; this is distinct from the discrete states for electrons in isolated atoms, shown schematically in figure 2(b). These energy levels extend throughout the lattice, and so the electrons in them are not spatially localized.

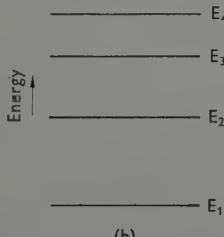
Inclusion of impurities or crystal defects (such as vacant lattice sites) gives rise to localized levels in forbidden zones, as shown in figure 2(a). In luminescence we are ultimately concerned with

the highest energy band which is filled by the original valence electrons of one of the lattice constituents; the next highest allowed energy band, which is empty; and the localized impurity centres or defect levels in the forbidden zone between these bands. Cathode-ray excitation (or excitation by ultra-violet radiation of sufficiently short wavelength) results in the raising of electrons from the filled band F to the empty or conduction band C. Empty levels are left behind in the valence band, and it can be shown quantum-mechanically that this is equivalent to having positively charged electrons in this band. These are called positive holes, because they are the result of the creation of vacant electron levels in the band. These positive holes can move through the crystal, as do the conduction electrons, under the influence of an applied electric field, but in the opposite direction to that of the electrons. The positive holes usually have a lower mobility than conduction electrons. On reaching occupied luminescence centres L they will capture electrons, thus emptying the centres and making them available for recombination of conduction electrons and radiation of the excess electron energy as luminescence. Thus in this case positive hole migration promotes luminescence efficiency. However, if conduction electrons are captured in lattice defect levels T (called electron traps), then the immobilized electrons will attract free positive holes and recombine with them, dissipating their excess energy thermally in the crystal lattice. This process offsets that of luminescence and, as shown by the author [3], it is, apart from secondary electron emission loss, the chief hindrance to the attaining of the theoretical maximum of efficiency in cathode-ray tube screens.

It will be seen that trapping effects, which are



(a)



(b)

FIGURE 2 - (a) Energy bands and levels for electrons in crystals. (b) Energy levels for electrons in an isolated atom.

usually responsible for the afterglow of phosphors by their storage and subsequent release of electrons, are a disadvantage to the efficiency of cathode-ray tubes. Commercial phosphors can now be made with an efficiency of 25 per cent for cathode rays; this means that three times the light-emission energy of the television screen is wasted, about half of it in warming up the screen. This has a further adverse effect on efficiency, since above a certain value this decreases with rise in temperature. Taking into account secondary emission losses, it may not be possible to exceed an ultimate efficiency of about 50 per cent for cathode-ray tube screens, however good the phosphor is.

(b) *Non-photoconducting phosphors* [1, 6]

Phosphors used for the internal coating of fluorescent lamps depending on low-pressure discharge are known as 'sensitized' phosphors. The main impurity used to activate the visible luminescence does not directly absorb the  $2537\text{\AA}$  radiation—the main effective radiation of discharge in mercury vapour—nor does the crystal lattice. To effect absorption and subsequent emission from the main activator a sensitizing impurity is introduced which has an absorption band at  $2537\text{\AA}$  and itself gives visible luminescent emission, usually at shorter wavelengths than that emitted by the main activator. The colour rendering of the lamp thus depends on the choice of the main activator and sensitizer, although in many cases alteration in lattice constitution can alter the relative intensities of the emission bands and so act as a convenient third variable for colour control. In the calcium halophosphates, for example, antimony is used as the sensitizing impurity, with manganese as the other activator impurity. The fluoride : chloride ratio in the halophosphate lattice serves as a secondary control of the colour of the light.

Figure 3 is a schematic spectral diagram for a typical lamp-phosphor. The fundamental problem involved here is the way in which, after absorption of radiation of wavelength  $2537\text{\AA}$ , the sensitizer atom S hands over the absorbed energy to the other activator A. This in fact takes place by a quantum-mechanical resonance process between sensitizer and sensitizer until it occurs between a sensitizer S and an activator A. If the excited sensitizer atom and a neighbouring unexcited atom (which may or may not be a sensitizer atom) can have the same energy in their excited states then there is a finite probability that a transfer of all the energy will occur between excited and unexcited atoms. This process will go on

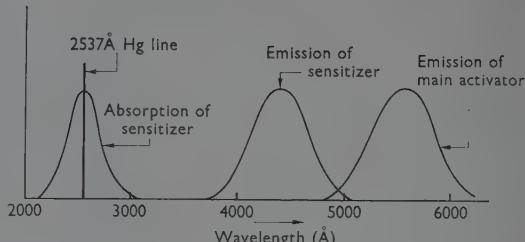


FIGURE 3—Schematic absorption and emission spectra for a fluorescent lamp phosphor.

between sensitizer atoms until the energy is degraded by a luminescence transition in the sensitizer or until a transfer to an activator occurs, a degradation can then occur by a luminescence transition in the activator atom. In some cases, e.g. calcium orthophosphate with cerium as sensitizer and manganese as activator, the distance over which S to S and S to A transfer is possible has been calculated from experimental data. Transfer may take place from a sensitizer to another sensitizer at any one of 150 neighbouring lattice sites. For S to A transfer the number is lower, namely 30, but in both cases the energy transfer is over distances much greater than those for adjacent lattice positions.

The efficiency of transfer can be markedly impaired, and of course both the efficiency and the colour of the lamp will then suffer, by the presence of 'quenching' impurities in which non-radiative degradation of the absorbed energy can occur. However, in spite of the need for great precision in choosing the ratios of sensitizer and activator atoms and of finding the right kind of host lattice, the modern fluorescent lamp is approaching the theoretical limit of its efficiency (see table, p. 147).

(c) *Electroluminescence* [1]

Figure 4 shows the energy band system in the phosphor crystals at one peak of the voltage cycle for the lamp illustrated by figure 1(a). A high field ( $> 10^7 \text{ V/cm}$ ) builds up at one side of the phosphor, and this is sufficient to eject electrons from normal states in centres into the conduction band. They are accelerated in the high-field region and produce further excitation by ionizing collisions, and by recombination cause emission of luminescence. The potential barrier picture shown reverses itself in each voltage cycle. For this kind of lamp special phosphors of the zinc sulphide class have been devised; they have a relatively high content of copper impurity and

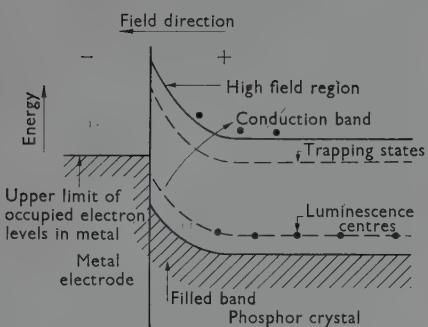


FIGURE 4—Energy band diagram for metal-electroluminescent crystal contact at peak applied voltage (metal negative).

their working efficiency is good. However, because of the fundamental nature of the electroluminescent process, efficiencies of more than a few per cent are hardly likely.

Another form of electroluminescence is that occurring when charge-carriers are injected into germanium or silicon carbide; the particular carriers represent only a small proportion of the total material. An example is injection of positive holes into germanium which is N-type, i.e. in which the normal electrical conductivity is predominantly due to electron motion through the crystal rather than to positive hole movement. When hole conduction is dominant the material is referred to as P-type. The injected carriers combine with those of opposite sign, giving up their energy as radiation. The process may take place through impurity centres. In some specimens emission due to hole injection has been observed as far into the infra-red as 60 000 Å. However, currents of many milliamperes must be injected in order to observe the emission, which has a very low efficiency.

The accompanying table summarizes the performance and intrinsic efficiencies of the three light sources discussed above; figures are also given for an ordinary tungsten filament lamp.

#### LUMINESCENCE IN ORGANIC CHEMICAL SYSTEMS [3, 7]

In organic systems, ionizing processes in excitation are in general injurious to the luminescence processes. However, for both high-energy particles and ultra-violet excitation of compounds, such as the crystalline aromatic hydrocarbons and their solutions, the luminescence process can be quite efficient and can involve large transfer of energy through the system, often by a process similar to that for the sensitized inorganic phos-

Light source	Intrinsic efficiency (per cent)	Theoretical limit of efficiency (per cent)	Practical efficiency in lumens/watt
Cathode-ray tube screen	25	75	up to 100
Low-pressure fluorescent lamp	~ 60	80	> 60
Electroluminescent lamp	~ 1	—	5–10
Tungsten filament lamp (gas-filled)	~ 2	—	10–15

phors discussed above. An example is provided by crystalline naphthalene containing a trace of anthracene. Absorption at shorter wavelengths in the naphthalene absorption bands is followed by almost complete transfer of the energy to the anthracene molecules, with subsequent emission as luminescence characteristic of these molecules. Again a quantum-mechanical resonance process is involved. In crystals, absorption in the molecular-absorption region of the spectrum produces photoconductivity. In anthracene the carriers appear to be positive holes. In liquid solutions, such as *p*-terphenyl in xylene, the solute molecules receive the energy absorbed in the xylene, but probably not by a resonance process. Each excited solvent molecule moves about until it collides with a solute molecule and hands over its excitation energy.

When larger, more complex, molecules are considered the exact interpretation of effects becomes very difficult. Examples are the luminescence of chlorophyll during the photosynthetic processes and the oxidation of luciferin in the firefly and other luminescent species [8, 9]. However, there is a possibility of applying theories developed for resonance transfer in the simple organic compounds to these biological systems. The fluorescent Scheibe polymer threads offer controllable material with large dimensions (thread length  $\sim 10^3$  Å); this lends itself to exact study and may provide a link between the simple molecules and the luminescent substances of plants or animals.

#### DETECTION OF NUCLEAR PARTICLES [4]

Some of the early studies of nuclear particles were made by Rutherford with a form of the Crookes' spinthariscope; this had a luminescent screen in which alpha particles produce scintillations which can be viewed through a lens. A

combination of a single-crystal phosphor and a photoelectric multiplier constitutes the modern form of the device (figure 5). The ultimate performance of such scintillation counters is set by the conversion efficiency of the phosphor and by the photoelectric efficiency of the multiplier. The phosphor efficiency depends on the nature of the particles or radiation being detected and particularly on the density of ionization produced. Inorganic crystals of the photoconducting type, in which—as shown above—the luminescence process is dependent on carrier liberation and transfer, will show approximately the same response for lightly as for densely ionizing particles. In contrast, in non-photoconductors, particularly organic crystals and solutions, ionization is deleterious to the luminescence process, which involves the resonance or collision transfer of energy respectively. Thus densely ionizing particles (protons, alpha particles, and so on of a few MeV energy) produce scintillations in these phosphors rather inefficiently. In addition, by their collisions with, and displacement of, the lattice atoms and by production of chemical dissociation as a result of the ionization, the phosphor is permanently damaged, its efficiency diminishing with dosage. The scintillation counter is notable for the speed of its response, the 'dead time' being in some cases less than  $10^{-8}$  second.

Recently Russian workers [10] have applied phosphor crystals to nuclear particle detection in a somewhat different way, as solid 'cloud' chambers for observing the particle trajectory. A form of this apparatus is shown schematically in figure 6. The particles are incident on a luminescent crystal and produce tracks of light within it. For very fast particles (such as high-energy protons) mesons may be produced in the crystal, and the 'stars' familiar in photographic emulsions used as detectors for cosmic rays can be obtained. The luminescent track is focused by a wide-aperture lens L

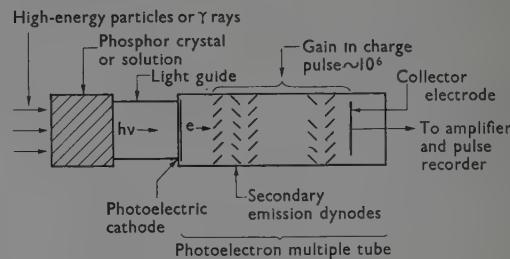


FIGURE 5—Schematic diagram of a scintillation counter for nuclear particles and radiation.

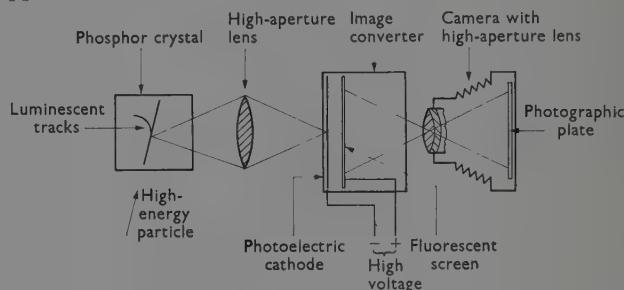


FIGURE 6—Schematic diagram of luminescent 'cloud' chamber.

on to the photocathode of an image converter I. The photoelectrons released in the latter are accelerated to high energies and impinge on a fluorescent screen to produce an image of the track in the crystal. The image converter provides the high gain necessary to observe the track. In the Russian form of the chamber a caesium iodide crystal with thallium impurity is used as detector.

#### CONCLUSION

It is clear to those working in the field that there is no comprehensive theory of luminescence covering all its mechanisms in liquids, gases, and solids and in biological systems. However, the problem of energy transfer processes provides a common, though as yet tenuous, link between them and determines their practical performance.

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# The study of organic evolution by observation and experiment

E. B. FORD

The Darwin Wallace Lecture of 1858 established evolution as the basic concept of biology. Only since the first war, however, has the process of evolution been observed and studied in natural populations. Indeed, the combination of ecological and genetic methods which has made this possible did not, for a considerable time, attract many research workers outside the small and scattered group who developed them in their early stages.

The occurrence of evolution, either in the immediate past or still in progress, can be inferred indirectly from the differences which exist between one and another population of plants and animals. Sometimes these are obviously related to the conditions of the habitats, more often their significance is obscure because we do not know enough of the genetics and ecology involved. For instance, a selective change has affected the Fool's Parsley, *Aethusa cynapium*, when growing in stubble-fields. Here it is smaller and flowers later than elsewhere, for the flowering heads of the normal strain are cut off by the reaping machine. We do not yet know the genetics of this situation, though we can be reasonably certain that the characters involved are polygenic. On the other hand, banded specimens of the Mottled Beauty moth, *Cleora repandata*, are in Britain almost confined to the west, where in some districts they comprise over 20 per cent of the population. The insect occurs in woods all over the country, but the banded pattern is unknown in the south-eastern counties. It is produced by a single gene incompletely dominant in effect, but there is nothing to indicate why its occurrence is related to certain areas.

The evolutionary divergence of a population into distinct races nearly always requires some form of isolation, as Darwin himself recognized, but the way in which this operates is a subject of acute biological controversy even today. In the first place, it is generally agreed that the subdivision of a population into small isolated units favours rapid evolution. This can usefully be illustrated by an example drawn from work on the Meadow Brown butterfly, *Maniola jurtina*, in the Isles of Scilly and elsewhere. In this insect the number of spots on the underside of the hind wing varies from 0 to 5. Their frequency-distribution in the males is everywhere the same, having

a single mode at 2 spots (figure 1). In the females, however, it has widely different values from one island to another, though, with a single exception to be noticed later, on each it has retained its characteristic form season after season.

The butterfly has been studied on five 'small' and on three 'large' islands in Scilly: the difference in area between the two groups is considerable, being seventeen times or more. The female spot-distributions are similar on all three large islands, the curve being approximately flat-topped with high frequencies at 0, 1, and 2 spots (figures 2-4). Yet they differ widely from one to another of the small islands: being unimodal at 0 or at 2 spots, or bimodal at these values (figures 5-7), while the modes may be greatly, or relatively little, accentuated. The similarity of the various large island populations and the dissimilarity of the small island ones has been explained in three ways.

It has been suggested that segregation in the genes which control spotting does not significantly affect individual survival, and that their chance distribution has produced differences in the small populations, which it could not do in the large ones. This is the concept of 'random drift', which has been advanced by Sewall Wright and others, chiefly in America. It is, in fact, of negligible importance in evolution; it is certainly not responsible for the situation just described, and this for several reasons. It can be calculated that random survival can outweigh the effects of selection only in small communities of a few hundred or less. None of the small islands in question carry populations of less than a thousand, and on several of them the total amounts to 18,000 or more. It has also been shown by R. A. Fisher [1] that gene substitutions of effectively neutral survival-value must be very rare. In the present instance, the observed stability of the spot-distribution on each

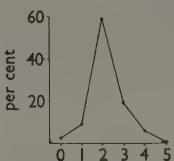
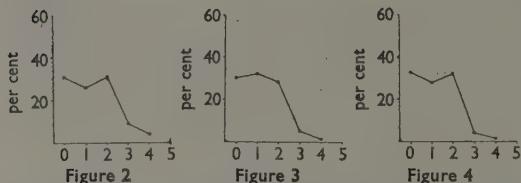
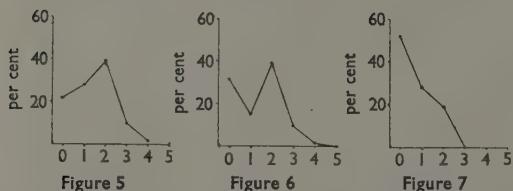


FIGURE 1—Distribution of spotting in male Meadow Browns.



FIGURES 2-4—Distribution of spotting in female Meadow Browns on three large islands. Figure 2, Tresco; figure 3, St. Martin's; figure 4, St. Mary's.



FIGURES 5-7—Distribution of spotting in female Meadow Browns on three small islands. Figure 5, St. Helen's; figure 6, Tean; figure 7, White Island.

small island is wholly inconsistent with the suggestion that this is subject to random drift.

Secondly, the theory has been advanced that at some period in the past the Meadow Brown may have become so rare in Scilly that the numbers on the small islands were reduced to a few specimens only. The chance characteristics of these individuals might then determine the type of population to be derived from them, while on the large islands enough specimens might remain to preserve the original characteristics of the race. However, that view does not appear to be tenable. First, if the various small island races reflect the chance qualities of a few butterflies surviving a former period of extreme scarcity, the genes responsible for spotting are not controlled by selection; and some of the difficulties inherent in such a concept have already been outlined. Secondly, one of the Meadow Brown populations on a small island (Tean) has been subject to a marked ecological change since our investigations began and to this it has evidently adjusted itself, for it is the only one in which the frequency-distribution of

spotting has altered to an extreme degree. But reduction to very small numbers, and subsequent repopulations from the survivors, was not needed to produce that change, for we studied the population throughout the period in question and we know that nothing of the kind took place.

Thirdly, when a population is subdivided into a number of small isolated groups, each can be adapted by selection to its particular local environment. But when continuous and occupying a larger area it can be adjusted only to the average of the conditions to which it is exposed. Such averages will vary relatively little from one large community or neighbouring island to another. This is the chief reason why isolation into small colonies favours rapid evolution, and it appears to be the one responsible for the similarity of the Meadow Brown butterflies on the large islands of Scilly and their dissimilarity on the small ones. The rapid adaptation to changing ecological conditions already mentioned favours such a view [2].

These alternatives are now being investigated experimentally. Over a hundred fertile females derived from a large island (St Martin's) have been used to found colonies on two small ones from which the insect was absent. Study of them in a few years, if they survive, may provide decisive evidence in favour of one of the theories here outlined.

Two subjects mentioned in connection with the Meadow Brown populations on Scilly deserve further comment. They can best be discussed with the help of examples. The Scarlet Tiger moth, *Panaxia dominula*, is a single-brooded species flying in July. It occurs commonly over about fifteen acres in a marsh near Oxford. The foodplant is Comfrey, *Symphytum officinale*, and the insect is restricted to the locality by surrounding woods and agricultural land. In this marsh a variety, *medio-nigra*, very rare elsewhere, is not uncommon. It is a heterozygote, the homozygous mutant, *bimacula*, being a much more extreme form. Both are characterized by an excess of black pigment, and, since all three genotypes are visibly distinct, the gene-frequency can be calculated by appropriate sampling. This has now been done each season since 1939: the gene has shown considerable fluctuations in frequency, on the whole declining from 9.2 to 1.0-2.0 per cent of the population. At the same time, the population-size has been calculated by the method of marking, release, and recapture.

With Mendelian inheritance it is possible to calculate the chance that a given change in gene-frequency is due to random sampling if the size of

the population be known, and in this instance the relevant data are all available over a long period. The result shows that the observed seasonal fluctuations in the occurrence of the *medionigra* gene are much too great to be ascribed to random survival, and must be due to selection, varying in intensity and direction from year to year. Thus in the first instance in which the possibility of 'random drift' can be directly assessed as an evolutionary agent, it can be decisively excluded.

An unexpected discovery has been made by P. M. Sheppard which throws some light on the maintenance of genetic diversity at the *medionigra* locus. In the laboratory, and presumably also in the wild, mating is not at random, but is influenced by a choice exercised by the females. These, whether *dominula*, *medionigra*, or *bimacula*, prefer to mate with either of the other forms rather than with their own. The sexes are in approximate equality, but while the males can mate many times the females do so once only. Consequently many males never pair. Such preferential mating will therefore favour *medionigra* males when the form is rare, and so tend to maintain the mutant gene. This, however, can be one only of the agencies responsible for its occurrence, and the changes in frequency to which it is subject, in this colony [3, 4].

Although extreme fluctuations in numbers are not likely to be responsible for the special characteristics of the Meadow Brown in Scilly, they are of great evolutionary importance. Indeed, I believe that plants and animals are far more subject to them than is generally appreciated; also that many populations generate such fluctuations autonomously, as it were. Natural environments are never constant, and when they favour a species its numbers increase and forms survive which would not normally do so. These are eliminated, and the numbers reduced, when the conditions become more rigorous again. Thus a numerical expansion prepares the way for a subsequent contraction. But the total effect is greatly to accelerate the speed of evolution; for the period of excessive variability, necessarily associated with it, allows new genic recombinations to become established, a process which would require a great length of time in a stable population. Any of them which may interact advantageously will be especially favoured when selection later becomes more severe. An example will make this clear.

A restricted colony of the Marsh Fritillary butterfly, *Euphydryas aurinia*, in Cumberland had remained remarkably constant in appearance while its numbers diminished from abundance to scar-

city, from 1897 to 1912. For the next seven years the insects were rare, but from 1920 to 1925 an extraordinary increase took place; by the latter year they could be seen in thousands. From 1926 onwards the population remained at this level. Variation became very pronounced during this rapid numerical expansion. Hardly two specimens were alike, and many of the more abnormal were deformed or even unable to fly. When, however, the numbers became stabilized at a high level, from 1926 onwards, variability declined, so that the specimens assumed once more a relatively constant form; this, however, differed from that which had characterized the colony before the outburst of variability [5].

In most of the instances so far described, it is not known what advantages and disadvantages the various forms confer, nor what are the selecting agents. That information has, however, been obtained more or less fully in some other species.

One effective type of adjustment to changing conditions is found in the heterostyle-homostyle mechanism of certain plants such as the primrose, *Primula vulgaris*. These are typically heterostyled: that is to say, the flowers on each plant belong to one of two alternative types, so arranged as to promote cross-pollination between them. Since primroses of one or the other form occur together indiscriminately, and in approximate equality in most populations, the situation is one which promotes outbreeding with consequent opportunities for genetic variability. It is controlled by a mechanism involving constant back-crossing, with segregation in a 1 : 1 ratio. Plants of one type, the thrum (with high anthers and short pistil), are heterozygotes, and those of the other, the pin (with low anthers and long pistil), are recessives. Even when the relatively uncommon self-fertilizations, or crosses between similar phases, occur, few seeds are set; this incompatibility is controlled by the same locus as that responsible for the pin-thrum distinction. However, another allelomorph, or perhaps 'super-gene', brings the anthers and style to the same height and annuls the incompatibility just mentioned. Consequently both the morphological and physiological barriers to inbreeding are removed in the resulting 'homostyle' plants. After a few generations, these therefore become approximately homozygous, with resulting genetic fixation. Thus such species can pass from outbreeding with great variability to any degree of inbreeding, depending upon the proportion of homostyles carried by the population; this is a very refined evolutionary adjustment to different

environments. It is one now being exploited by the primrose in Somerset; homostyles are spreading until they constitute a considerable proportion of the plants in part of that county.

The basis of natural selection has been analysed more fully in other species. The land snail, *Cepaea nemoralis*, is polymorphic for colour-pattern, i.e. various forms differing in appearance coexist in the same population in such proportions that even the less frequent among them are too common to be maintained merely by the rare process of recurrent mutation. These differences are genetically controlled. Pink shells are dominant to yellow, and brown are dominant (or epistatic) to pink; the absence of bands is dominant to their presence.

A. J. Cain and P. M. Sheppard [6] have studied this situation in many localities, and in the majority of them birds are the chief predators: especially the Song Thrush, *Turdus ericetorum*, a species which breaks the shells of its victims on convenient stones or 'thrush anvils'. Yellow shells are the commonest on green backgrounds, and banded on variegated ones. On such a uniform and brown background as that provided by a beech wood, brown unbanded shells are much the most abundant. It is found that inappropriate shell-types appear more often among the snails destroyed by thrushes than those better suited to the environment, as can be seen by their remains at the anvils. Moreover, in two open deciduous woods studied in detail, the proportion of the yellow form killed by thrushes declined from mid-April to mid-May, as the areas became greener. By marking large numbers of living snails, it was shown that this change was not due to the birds shifting their feeding grounds or to a decrease in the yellows among the population as a whole. It was, in fact, the result of visual selection by predators, affecting the frequency of certain genes in the snail population. As with the Meadow Brown in Scilly, it has in the past been claimed that 'genetic drift' accounts for the differences in proportion between the phases of this snail from one locality to another, a conclusion now clearly refuted.

The most striking instance of evolutionary response to changed conditions is provided by the

industrial melanism of moths. During the last hundred years about seventy species have become black, or very dark, in manufacturing districts in Britain, where over 95 per cent of the population is sometimes affected. A similar occurrence has been observed in some other countries. These blackish forms are nearly always controlled by single genes, which are dominant or semi-dominant in effect. The change is due primarily to smoke pollution from factories and railways throughout such areas, and extending far beyond them carried by prevailing winds. The pollution not only blackens tree-trunks and rocks, but prevents the growth of lichens which normally make such surfaces paler than they otherwise would be.

The species are all such as sit fully exposed, protected by their cryptic coloration. H. B. D. Kettlewell [7], working on the Peppered Moth, *Biston betularia*, has shown that predators eliminate more of the black than of the pale form in unpolluted woods, while the converse is true in industrial regions. The species concerned are birds; Song Thrushes, *Turdus ericetorum*, Flycatchers, *Muscicapa striata*, and others, which feed upon the moths when resting upon tree-trunks and boughs, picking out the more conspicuous specimens.

Kettlewell's large-scale experimental studies have shown not only that birds attack moths when resting upon trees, but that they do so in great numbers. No animals are collected so much as butterflies and moths, nor observed so assiduously as birds, yet entomologists and ornithologists have until now been unaware of such predation and have indeed for generations strongly denied it. Furthermore, the Meadow Brown is one of the commonest British butterflies, yet the remarkable sexual difference in its spotting was discovered only in 1947, while the fact that thrushes prey selectively upon snails was not fully established until 1950 for banding and 1951 for colour. Indeed, those naturalists interested in biological problems, rather than in groups of animals or plants, can make striking discoveries in regard to the most familiar species; while ecological and genetic methods can now be used to demonstrate the occurrence of evolution in wild populations and to analyse it experimentally.

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# Electron microscopy: its scope and limitations

V. E. COSSLETT

Recent improvements in the methods of preparing material for electron microscopy, and especially in the technique of cutting sections, have made the method applicable in almost the whole field of classical microscopy, apart from the observation of living material. This authoritative article reviews the progress made in the study of the fine structure of both biological and inorganic material, the scope and limitations of the method, and the principal difficulties that are encountered in the unambiguous interpretation of results.

The first reports of success with an electron microscope appeared early in 1932 [1]. The types of electron lenses, electrostatic and magnetic, which had been developed primarily for the cathode-ray tube had been adapted to form magnified images. The electrostatic lens has carried the day in the oscilloscope, but the magnetic type has come into almost general use for microscopy. Today, within less than twenty-five years, the electron microscope has made for itself a place of some importance among research tools for investigating the micro-structure of matter. Ernst Ruska, who built the first magnetic electron microscope as his *Diplomarbeit* in the *Technische Hochschule* of Charlottenburg, later designed a production model for Siemens and Halske, and has continued to direct their electron optics section ever since. He still leads in the construction of electron microscopes of high performance. The new Siemens Elmiskop has a resolving power of 10 Å or better. All the major industrial countries now manufacture electron microscopes, Japan in the largest numbers, but the only serious rival to the Elmiskop is the Metropolitan-Vickers EM6, the prototype of which was shown

at the 1956 Exhibition of the Physical Society in London.

What can today be expected of electron microscopy is best seen by considering the range of dimensions of natural structures (figure 1), from the limit of resolution with the unaided eye (0.25–0.1 mm) to the size of an atom (2.5–1 Å). The limit of optical microscopy, using ultra-violet light, lies just half-way down this range: the

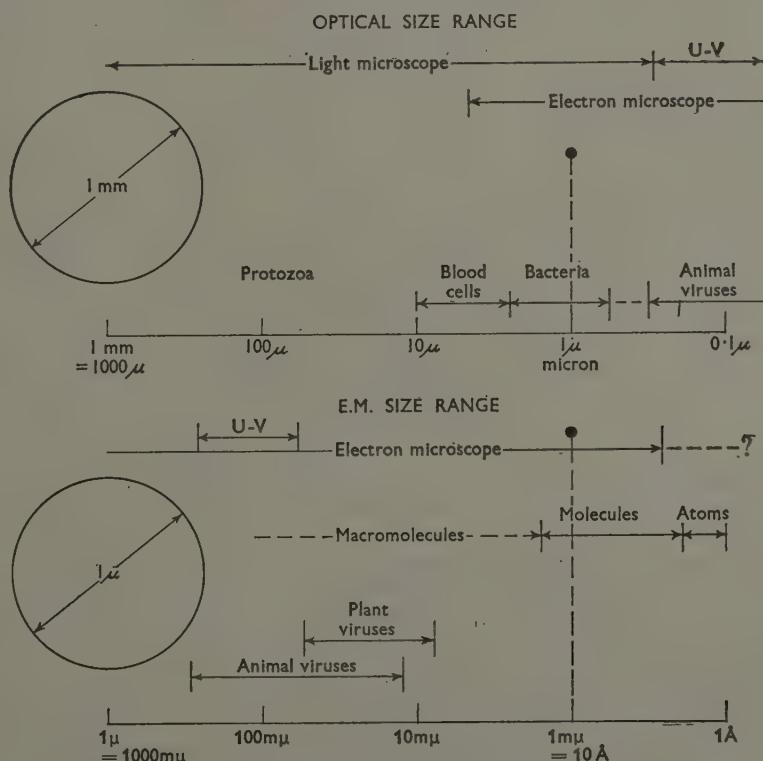


FIGURE 1 — Size range for optical and electron microscopy.

electron microscope may be expected ultimately to attain a resolving power of atomic order, so that it should double the range of microscopical investigation. In rough terms, the use of a simple lens increased our optical range tenfold, the combination of two lenses to form a compound microscope added another order of magnitude, and the improvements of the past century in optical microscopy added yet another. The first electron microscope gave a similar step forward and the refinements of the past two decades still another tenfold advance. Research now in progress in several laboratories, primarily in Germany and Great Britain, offers reasonable prospects of carrying the limit from  $10\text{ \AA}$  down to  $1\text{ \AA}$ ; the present limit in experimental microscopes lies around  $5-6\text{ \AA}$ .

The value of such a resolving power depends, of course, on what there is to be seen beyond the normal optical limit. In biology it was already clear that there existed a whole range of animal and plant viruses, as well as the macromolecular components of larger organisms, which would repay detailed investigation. In fact, electron microscopy has revealed a new world of microstructures in all tissues and even in viruses themselves. In the inorganic world, dusts and powders, precipitates and colloidal suspensions, were obvious subjects, but it was not at all clear whether any fine structure was to be found in metals in the range between the etch patterns visible in the optical microscope and the atomic lattice. Here the electron microscope has been able to show the reality of steps and spirals and other features of crystal growth, as well as of the slip lines and bands which are produced in plastic deformation. The postulate of the existence of dislocations, in explanation of these and other phenomena, has set a new goal for electron microscopists—to make visible the lattice itself and imperfections in it (see figure 14). This goal has already been attained with certain molecular crystals.

#### THE INSTRUMENT

The general lines of the instrument follow those of the optical microscope: a condensing system projects illumination on to the specimen, which lies in the focal plane of the objective, and a subsequent lens provides additional enlargement. The differences of principle and construction follow from the essentially different nature of the two forms of illumination. Light, an electromagnetic wave motion, is focused by the fields within certain

solid or liquid aggregations of particles (transparent media). Electrons, a particulate radiation, are focused by electromagnetic fields of appropriate distribution, and are scattered by other particles. This latter phenomenon is a disadvantage in that it requires the electron path to be in high vacuum, but on the other hand it is the primary source of image contrast: various parts of the specimen will appear light or dark, depending on differential scattering of electrons. Micrographs of graded density are thus obtained, not mere silhouettes, provided that the specimen is below a certain thickness: this is of the order of the wavelength of violet light ( $3000\text{ \AA}$ ).

The wave nature of the electron need be invoked only when a quantitative treatment of image formation, and in particular of resolving power, is required. Apart from lens aberrations, which are severe, the ultimate limit to resolution is set by the equivalent wavelength of the illuminating electron beam, which depends inversely on the square root of the accelerating voltage. A high voltage is thus needed, and for the range most in use (50–10 kV) the equivalent wavelength varies from  $0.054$  to  $0.037\text{ \AA}$ . A resolving power several orders beyond that of the optical microscope would therefore be expected, even with electron lenses which correspond in crudity to the early uncorrected lenses of glass optics. The working magnification of an electron microscope needs to be correspondingly higher. An image in which points separated by  $10\text{ \AA}$  are resolved has to be enlarged until they are more than  $0.1\text{ mm}$  apart if the eye is to appreciate all the recorded detail, i.e. by at least 100 000 times. For ease of viewing, and to allow for better resolution than  $10\text{ \AA}$ , another power of ten is desirable, and many micrographs are now reproduced at a useful magnification of the order of one million times. Such a high value is not attained directly in the electron microscope, as it would require an electron source of higher power than any yet available, unless an image intensifier were to be used for viewing the picture. Direct magnifications up to 100 000 times or more are provided (in the Elmiskop, up to 160 000 times) and a viewing telescope is used when focusing the image.

The construction of an electron microscope of modern design is shown schematically in figure 2, with ray paths for medium high magnification. The beam from a triode electron gun is projected through the anode diaphragm A, at earth potential, into a two-stage condenser, C<sub>1</sub> C<sub>2</sub>, which throws a beam, the intensity and

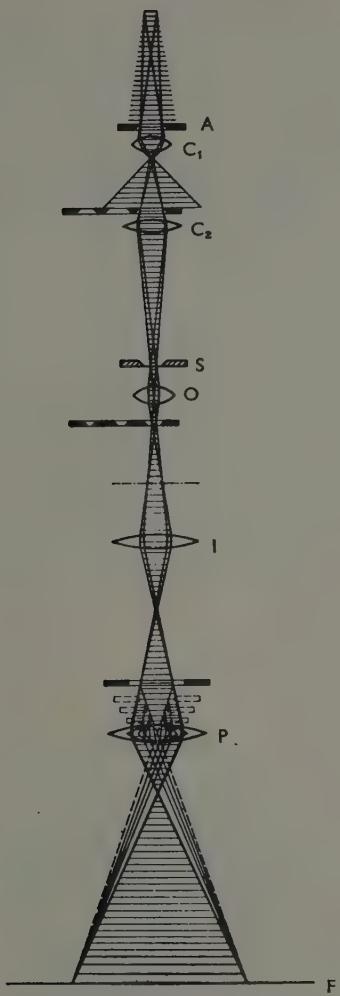


FIGURE 2 - Electron paths in electron microscope of high power.

cross-section of which can be varied, on to the specimen S to be examined. The system is highly efficient and provides illumination enough for magnifications up to 160 000 times and an illuminated area small enough to keep the temperature of the specimen from rising by more than a few tens of degrees. The imaging system consists of the high-power objective O, followed by an intermediate lens I and a final projector lens P; the maximum stage magnifications are of the order of  $\times 200$ ,  $\times 10$ , and  $\times 100$  respectively. Electron diffraction may be practised by focusing on the back focal plane of the objective instead of on the specimen. For photographing, the fine-grained fluorescent screen F on which the image

is viewed can be raised; plates are preferred to film for high-resolution work. The body of the instrument is continuously evacuated with high-speed pumps, and specimens are introduced through an air-lock. The high-voltage supply and the current for the windings which excite the magnetic lenses must be stabilized to the order of 1 part in  $10^5$  in order to provide a monochromatic beam; this is normally done in a separate unit in order to keep disturbing fields at a distance from the microscope. The lenses consist of windings within an iron casing, the field being concentrated on the axis between conical polepieces of small bore; the excitation may be as high as 5000 amp. turns and the focal length as small as 1 mm. Of the various aberrations, only the astigmatism arising from lack of rotational symmetry of the field can at present be corrected, by means of trimming fields generated by a 'stigmator' fitted into the objective; these can be varied in strength and azimuth while the effect on the image is observed. It is also most important for all the lenses to be centred on the same axis, and each is provided with transverse shift controls for this adjustment; the condenser system may also be tilted about the specimen position.

#### APPLICATIONS IN BIOLOGY AND MEDICINE

The first and obvious use of the electron microscope in biology was for the sizing of living particles too small to be measured in the optical microscope: bacteria, rickettsia, animal and plant viruses, and bacteriophages. A great deal has been done and continues to be done in this field. Studies have also been made of the external morphology of micro-organisms, such as the flagella of bacteria and spirochaetes, and of their detailed structure in so far as it can be revealed through degradation by thermal and mechanical treatment, enzymatic action, and selective extraction. Much has been learnt in this way about the bacterial cell wall, the mode of action of bacteriophage, and the effect on the morphology of bacteria of the medium on which they are grown, for instance. But the whole use of the electron microscope in biology has been revolutionized by the recent development of the technique of cutting thin sections, which has at last opened up the study of bulk tissues to electron microscopy.

As developed for optical microscopy the microtome could cut sections as thin as 1 micron but rarely thinner. Since doubts were expressed, on theoretical grounds, about the possibility of cutting very much thinner sections by the classical

methods, attempts were at first made, especially in the United States, to cut at extremely high speeds, for instance by fitting the knife or specimen in the edge of a wheel or even of a centrifuge disc. The aim was to minimize the effect of the shock wave ahead of the cutting edge. Little came of these experiments, and it was not long before L. H. Bretschneider in Delft, and D. C. Pease and R. F. Baker in the United States, showed that microtomes of conventional design could be made to cut sections at least down to 0.1 micron thick by refinement of the advance mechanism [2].

The resolution obtained in the image of a section depends upon its thickness, because of the confusion produced by inelastically scattered electrons [3]. The resolution is about one-tenth the thickness, so that specimens as thin as 100 Å must be cut if full advantage is to be taken of an instrumental resolving power of 10 Å. Attention has therefore been directed to special microtome systems, designed to give greater thermal and mechanical stability and improved regularity of sectioning down to 100 Å and below. The types which have found most favour are those which employ controlled thermal expansion for advancing the specimen. When sections as thin as a tenth of the wavelength of light are being cut, it is important to prevent the specimen block brushing against the knife, to which the cut section is adhering, on the way back to its undisplaced position. Such a single-pass action is attained in a variety of ways: by rotating the end of the rod carrying the specimen (F. S. Sjöstrand [4], A. J. Hodge, H. E. Huxley, and D. Spiro [5]), by guiding it through a gate by a cam system (K. R. Porter and J. Blum [6]), or, most neatly, by making the rod of nickel and utilizing magnetostriction (H. B. Haanstra [7]). The last named has produced the thinnest sections (60 Å) and the best evidence of repetitiveness. For ultra-microtomy, as it has come to be called, a very hard embedding material is required, and the usual method is to embed in monomeric methacrylate, which is then allowed to polymerize. A lozenge of cut glass is found to give the best cutting edge; but it soon deteriorates, and attention has returned to refinements in sharpening the normal type of microtome knife or safety-razor blades. A full account of present technique is given in a review by Sjöstrand [8].

The wealth of information revealed by these new methods can be compared, in fascination as well as in quantity, only with that which came from the first microscopical explorations of Hooke and van Leeuwenhoek. Every type of tissue exa-

mined has been found to contain a great complexity of membranes, canals, and particles, ranging through the macromolecular domain down to the limit of observation. The vital processes of the cell are shown to depend on a most intricate microstructure, which is rapidly being mapped. It is possible here to indicate only some of the main features which have emerged.

The cytoplasm of many animal cells—kidney, liver, pancreas, nerve, and so on—contains a ramifying system of double membranes, to which particles often appear to adhere (figure 3). G. E. Palade and Porter [9] suggest that this is a fundamental feature of all tissue and name it the 'endoplasmic reticulum'; it appears also in discrete bodies, such as the mitochondria, which occur in the cytoplasm. Sjöstrand, however, already distinguishes at least three forms of 'cytomembranes'. Detailed serial sectioning is now needed to show what may be true membranes and what may in fact be canals. Work is actively proceeding on the architecture of specialized regions of the cell such as the so-called Golgi apparatus, which is now shown as a complex of vacuoles, membranes, and particles. Of the greatest interest are the extraordinarily regular arrays of parallel plates which have been found in chloroplasts and in the retinal rods. Electron microscopy has also revealed fine structural detail in nerve cells [41].

In comparison with the richness of detail discovered in the cytoplasm, very little has so far come out of studies of the cell nucleus and in particular of chromosome structure. It has been conclusively proved, as had long been suspected, that small pores exist in the nuclear wall, permitting passage of the contents to the cytoplasm and *vice versa*. But the nucleus itself has seemed singularly devoid of structure. It is possible that this is indeed the normal condition and that microstructure exists only at certain periods of the cell cycle. It is more probable, however, that structure is destroyed during the fixation and embedding processes. Here, as in many other biological problems, a co-ordinated attack with optical and electron microscopical techniques is required. In a recent comparative study, I. R. Gibbons and J. R. G. Bradfield [10] have found that the methods of fixation with osmium tetroxide, normally so successful for the cytoplasm, show hardly any differentiation between chromosomes and nucleus (figure 6) in conditions where ultraviolet microscopy shows them to be highly defined. Formalin fixation gives rather better contrast between chromatin and nuclear sap. Much more



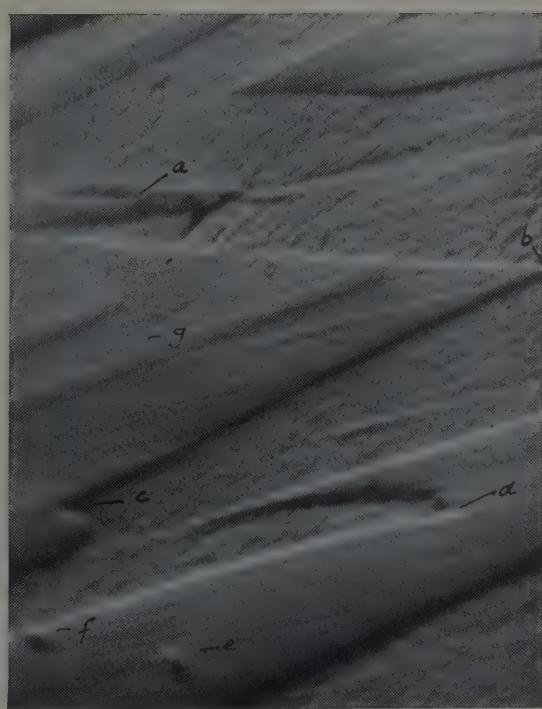
FIGURE 3—Section of pancreas, showing cytoplasmic membranes and adhering particles. (By courtesy of Professor F. S. Sjöstrand and 'Experimental Cell Research'.)



FIGURE 4—Tubercle bacilli, bovine strain. Thin section of lung of infected mouse, showing dense filamentous bacteria in vacuolized cytoplasm. (Dr E. M. Brieger and Miss A. M. Glauert, Strangeways Laboratory, Cambridge.)



(i)



(ii)

FIGURE 5—Surface of 60-40 brass, lightly etched. (i) Optical micrograph. (ii) Reflection electron micrograph at a foreshortening of 1 in 7. Corresponding features in the two prints are labelled a, b, c, etc. (Dr D. Jones, Cavendish Laboratory, Cambridge.)



FIGURE 6—Cell nucleus, in prophase of meiosis, from testes of *Locusta migratoria*. Transverse bands are knife-marks. Inset: Ultra-violet micrograph of same nucleus; succeeding section. (Mrs A. Cosslett and Mr I. R. Gibbons, Cavendish Laboratory.)

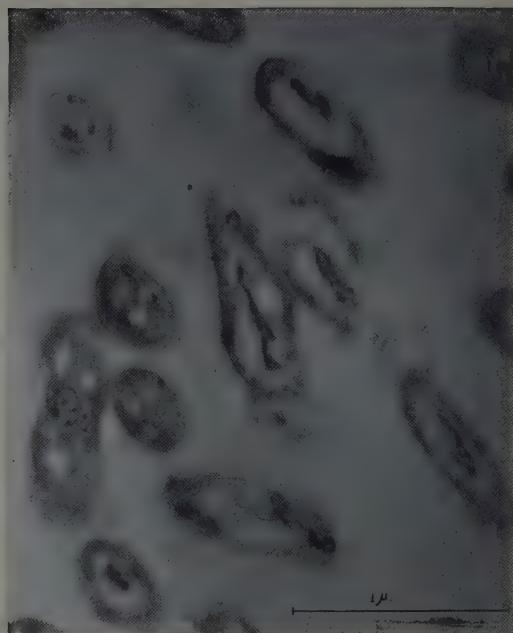


FIGURE 7—Tubercle bacilli, avian strain. Thin section of artificial culture after 24 hours' growth, showing complex internal structure. (Dr E. M. Brieger and Miss A. M. Glauert, Strangeways Laboratory, Cambridge.)

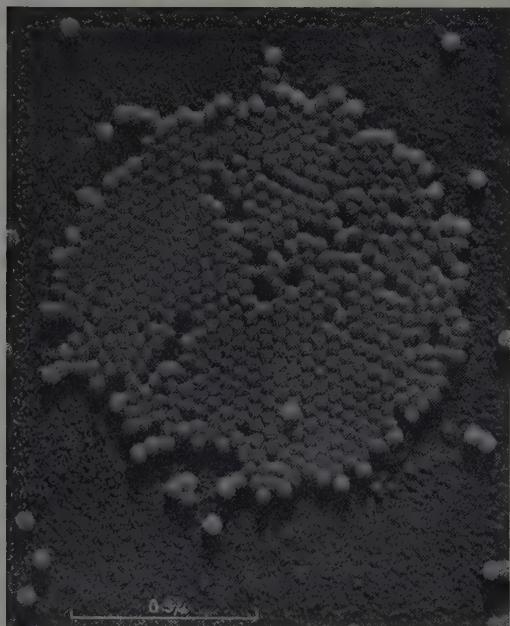


FIGURE 8—Virus of poliomyelitis, metal shadowed. (Dr R. C. Williams, Virus Laboratory, University of California.)



FIGURE 9—Turnip yellow virus. Isolated particles are polyhedral, not spherical. Carbon replica. (Dr R. Markham, A.R.C. Virus Research Unit, Cambridge, and Mr R. W. Horne, Cavendish Laboratory.)



FIGURE 10—Laths of cementite, from pearlite. Extraction replica. (Dr J. Nutting and Mr E. Smith, Department of Metallurgy, Cambridge.)



FIGURE 11—Precipitates from a chromium-molybdenum steel. A is  $\text{Fe}_3\text{C}$ , B is  $\text{Mo}_2\text{C}$ , and C is  $\text{Cr}_3\text{C}_2$ . Extraction replica. (Dr J. Nutting and Mr E. Smith, Department of Metallurgy, Cambridge.)

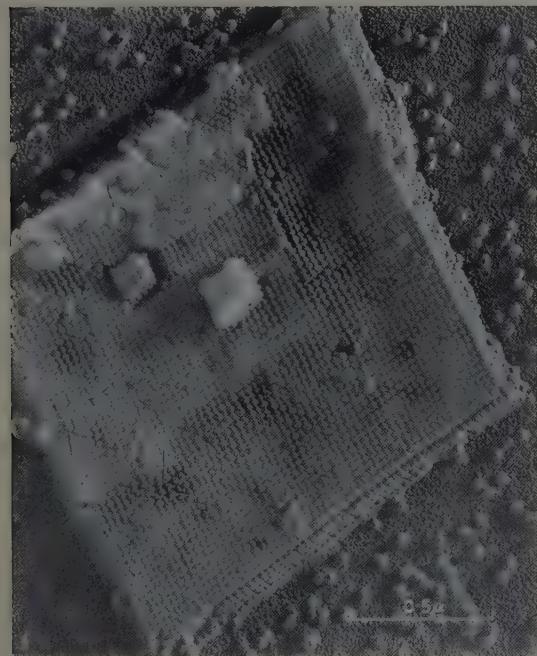


FIGURE 12—Tobacco necrosis virus crystal; carbon replica of metal-shadowed preparation. (Dr R. W. G. Wyckoff and Dr L. W. Labaw, National Institutes of Health, Bethesda, Maryland.)

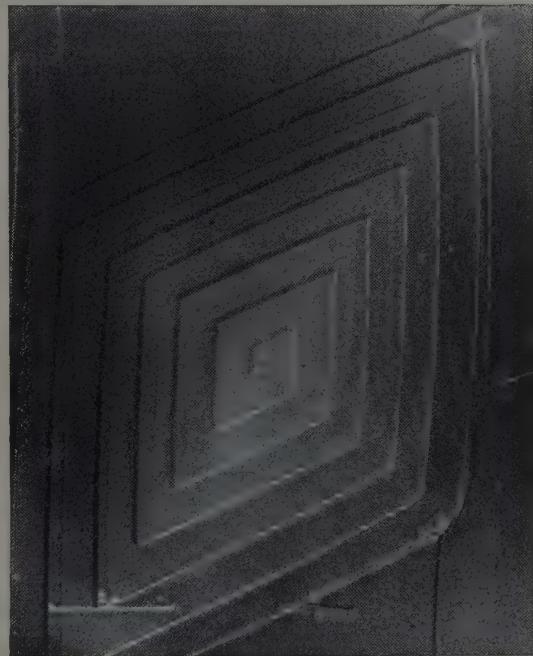


FIGURE 13—Single crystal of n-heptane, showing spiral growth front arising from a single dislocation centre; shadowed with palladium. (By courtesy of Dr I. M. Dawson, University of Glasgow.) (Proc. roy. Soc. A., 214, 72, 1952.)



FIGURE 14—Platinum phthalocyanine, showing edge dislocation; 201 planes, spacing 11.97 Å. (Dr J. W. Menter, Tube Investments Research Laboratories, Hinxton Hall, Cambridge.)

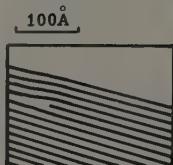


FIGURE 15—Slip steps in heavily deformed  $\alpha$ -brass. Silicon monoxide replica. (Dr H. Wilsdorf, National Physical Laboratory, Pretoria, South Africa.)



FIGURE 16—Copper phthalocyanine, showing 201 planes, of spacing 10.30 Å. (Dr J. W. Menter, Tube Investments Research Laboratories, Hinxton Hall, Cambridge.)



FIGURE 17—*Staphylococcus aureus* in thin section. (Dr J. R. G. Bradfield, Cavendish Laboratory, Cambridge.)

definite structure is found in the heads of spermatozoa, which are known from their birefringence to contain a degree of orientation.

This example stresses the present need in electron microscopy for that same detailed and painstaking investigation of methods of fixation, embedding, and staining as was undertaken in the classical work of Hardy and others in optical microscopy at the end of the last century. We need to know much more about the effect of reagents on the cell at a much lower level of structure than those workers were concerned with, and indeed right down to the molecular organization. Artefacts of drying, on the other hand, are less severe than was at first anticipated. The new field of micro-cytology calls for its own micro-histological techniques, and it is to be expected that these will differ greatly from the established macro-methods. In order to make many structures visible in light a great deal of precipitation and aggregation of cell contents must undoubtedly

be produced. For instance, G. Rosza and R. W. G. Wyckoff [11] have shown that some of the fibrous appearances classically associated with mitosis are hardly to be seen at all in electron micrographs; their reality at the molecular level is shown by their birefringence in the living dividing cell. The preservation of macromolecular structure is one of the main tasks in the perfection of the technique of preparing specimens for electron microscopy. In solving it, what has been learned from the development of classical microscopy is likely to be more than repaid in the refining and elucidation of structures which optical methods necessarily can show only crudely, even if they do not distort them or destroy them altogether. An attempt at such a refinement of technique has been made in Sjöstrand's laboratory [12] in respect of the alkaline phosphatase long known to exist in the brush border of the intestinal epithelium.

In its medical applications also, electron microscopy now needs more critical and fundamental

investigations. Studies of pathological conditions have been pushed ahead before we know very much of the microstructure of the normal cell or of infective agents in isolation. For instance, early claims of the existence of virus-like bodies in cancerous tissues have been followed by the demonstration that in many cases most if not all of these particles occur in the normal healthy cell: the necessary painstaking comparative work is now being undertaken in the leading cancer research centres. In the case of tuberculosis the situation is rather farther advanced, in that we now have evidence that the appearance of the bacillus in infected tissues is very different from what it is in cultures (figures 4 and 7). Thin-sectioning technique has now made possible the systematic investigation of the infective agent, whether virus or bacterial, in the host. Some work has been done with leprosy as well as with tuberculosis, but very much more with plant and animal viruses. The location of the infection, whether in nucleus or cytoplasm, can be found, and the stages in the development of the agent followed. In most cases these are proving to be more complicated than expected, especially with plant viruses. Studies of the effect of therapeutic agents, such as antibiotics, have been reported.

Investigation of the internal structure of isolated bacteria and viruses and other micro-organisms has also followed upon the development of ultramicrotomy. Some account of the structure of spermatozoa was given in a recent issue of this journal by Lord Rothschild [13]. Bacteria, far from being just sacs full of assorted enzymes, are found to have quite complex internal structures. Coccii show a central nucleus surrounded by cytoplasm exactly as in larger cells (figure 17); silver staining proves the nucleic acid to be located in the central region, which in unstained sections contains well defined threads that might be the genetic material (Bradfield [14]). Rod bacteria, however, show an extended nuclear region, the ramification of which depends on the age of the culture. In aureomycin-treated cells E. Kellenberger and A. Ryter [15] find more nearly spherical vacuoles containing fine threads, similar to the nuclei of coccii, but they are doubtful of identifying them as nuclei and chromosomes. It is now well established, however, that the bacterial nucleus is usually a region of lower density than the cytoplasm, as first indicated by C. F. Robinow [16]. Many species regularly contain dense round bodies, which have been variously claimed as mitochondria, nuclei, and spores. A

careful study by A. M. Glauert and E. M. Brieger [17], in which the same cells were photographed in both the electron microscope and the optical microscope, after application of a number of standard staining processes, showed that the bodies failed to respond to the normal tests for either nuclei or mitochondria. They contain metaphosphates and probably ribonucleoprotein, but not deoxyribonucleoprotein, and are probably to be classed with the metachromatic volutin granules observed by other workers.

Many of the larger animal viruses have been shown to have a degree of organization since the original demonstration by I. M. Dawson and A. S. McFarlane [18] of a central dense region in vaccinia virus, probably to be identified as a nucleus. The smaller animal viruses, such as that of polio (figure 8), and the spherical plant viruses, have not yet been shown to have structure and may be single macromolecules, although the existence of two forms of turnip yellow virus, one containing much more nucleic acid than the other, would indicate that the latter substance occupies a definite position. In tobacco mosaic virus, beautiful work by G. Schramm and his school [19] has shown conclusively that the nucleic acid fibres form the core of the rod, on to which 'beads' of protein are threaded. R. C. Williams [20] has shown that the rods are hexagonal in cross-section but found free-lying nucleic acid fibres of about half the diameter of those found by Schramm (34 Å). The availability of microscopes of much higher resolution than those with which these investigations were made will allow still finer details of virus structure to be demonstrated. R. Markham and R. W. Horne [21] have, indeed, already shown that turnip yellow virus particles are not spheres, as they appear to be at poorer resolution, but have a definite crystallographic form which agrees with their macroscopic habit in crystal formation (figure 9).

These virus problems apart, the main task in biological applications of the electron microscope is the refinement of preparative methods. Very few specimens, including thin sections, show a resolution better than 20–30 Å. If smaller macromolecular detail is to be made visible, as the instrumental resolving power would allow, we need careful investigation of the factors limiting present methods, in the hope that means of preserving finer structures will be found.

#### METALLURGICAL APPLICATIONS

Since all metal specimens of interest, except very thin films, are impenetrable to the electron beam,

replica techniques were early devised for studying surface structure. Plastic films, such as nitro-cellulose and Formvar, have been much favoured, but many other materials have also found use, especially evaporated films of silica, silicon monoxide, and some metals. A great deal of useful information has been obtained in this way about the detailed structure of fracture surfaces, grain boundaries, slip bands, and many other features which occur naturally, or after etching, on the surface of a wide variety of metals. Two recent developments have greatly extended the scope of the electron microscope in metallurgy, and indeed for surface studies generally: the discovery of a replica technique of much better inherent resolution than any hitherto known, and the perfection of reflection microscopy and other means of directly examining the surface of a solid specimen.

Most replica methods used until recently were limited, primarily by self-structure, to a resolution of the order of 200 Å; silicon monoxide gave rather better results. The carbon replica method devised by D. E. Bradley [22] appears not to suffer from this defect, at least down to a resolution of 10 Å. The carbon is evaporated from an arc and is deposited either directly on the specimen or on a thick primary replica in a plastic material. The carbon film, which is usually about 100 Å in thickness, is then floated off in a suitable solvent and mounted in the usual way for electron microscopy. The films are surprisingly strong and may be handled and examined in the electron beam without undue precautions; Bradley has successfully used films as thin as 25 Å. On account of its toughness the carbon film is coming into wide use as a specimen support, especially for thin sections, for which only the very minimum of extra scattering matter can be tolerated in high-resolution microscopy. The carbon film is also the basis of the extraction replica method due to J. Nutting and E. Smith [23], by which the arrangement of precipitated material in a surface may be preserved for study by electron microscopy and diffraction. After carbon has been deposited on the surface, the main body of the metal is removed by immersion in a suitable reagent. The carbon film floats free, bearing in it any insoluble precipitates that were in the metal surface. The material from a normalized and tempered chromium-molybdenum steel is shown in figure 11; electron diffraction identified the three components as carbides of iron, molybdenum, and chromium. The method is finding a wide variety of applications; figure 10 shows laths of cementite extracted from

pearlite, the preferred orientation in which was then proved by electron diffraction.

The direct observation of surfaces by electron reflection was briefly investigated in 1939-40 by German workers, and was revived in Cambridge after the war [24]. The principle is shown in figure 18. The illuminating system of the electron microscope is tilted through an angle of some 10°, so that the beam falls on the specimen surface at an angle of the order of 1°. Scattered electrons (it is in no sense a specular reflection) pass into the aperture of the objective lens and form an image in the usual way, except for the foreshortening due to the inclination of the specimen. This angle is usually about 8°, so that the image is foreshortened in the ratio 1 : 7; the transverse and longitudinal magnifications differ in the same degree, so that angular relations are distorted. Comparison with a normal optical picture (figures 5(a) and (b)) shows that care is called for in interpreting the micrographs. Recently, however, excellent results have been obtained by C. Fert [25] at a foreshortening of only 1 : 2; resolution is even better than at a ratio of 1 : 7, but exposure times are longer.

The advantage of the reflection method is that it allows direct observation of a surface during treatment, which may be thermal, mechanical, or chemical. D. Jones [26] has obtained micrographs of a silver surface at temperatures up to 900°C. with a miniature furnace built into the specimen stage. A wide variety of surfaces has been investigated by J. W. Menter [27]: they include diamond, rayon, and other non-conductors, which give satisfactory images if first coated with an evaporated layer of silver. When the surface is rugged, or is difficult to replicate by the usual techniques, the reflection method is of value even when no treatment is desired. It has the disadvantage, however, of a relatively poor resolution, the best results being not better than 250 Å. The cause of this lies in the wide scatter of velocities in the 'reflected' electron beam, and little improvement is likely until an achromatic lens can be designed. Meanwhile the reflection method is finding many applications, especially in industrial laboratories.

A number of other techniques for surface investigation have been devised. D. McMullan [28] has revived and improved the scanning or flying-spot microscope, in which a fine electron spot is scanned across a surface, the scattered electrons giving a signal which is amplified and displayed on a synchronously operated cathode-ray tube. The

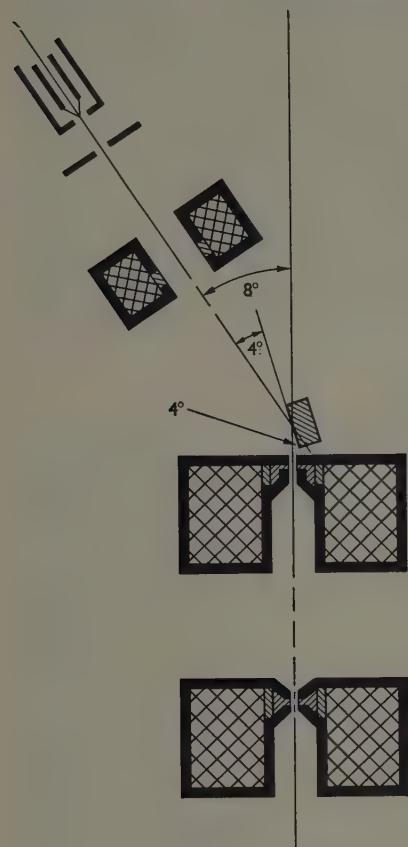


FIGURE 18—Principle of reflection electron microscopy.

resolution so far obtained is barely as good as that of the standard reflection technique; but the method has certain advantages, and a commercial model is to be produced. G. Möllenstedt and H. Düker [29] have employed an ion beam for bombarding a surface, the ejected electrons being collected and imaged in an objective lens in the usual way. The micrographs so far shown have a resolution at least as good as that of the reflection method and a striking three-dimensional appearance, which may be due to etching of the surface under bombardment. Microscopes have also been constructed in which the cathode itself is the specimen, images being formed with the thermally emitted electrons. Interesting results have been shown of phase changes at high temperatures in iron, molybdenum, and other metals [30]. A commercial model of this emission electron microscope has now been produced by Philips of Eindhoven.

All these techniques are finding applications,

and in this sense metallurgy is better served by electron microscopy than is biology. So far, however, almost all the work published has been on the fundamental chemistry and physics of the subject and has not yet been reflected in routine analytical or etching procedures. In an endeavour to ensure uniformity in basic methods, an important step in establishing routine techniques, the American Society for Testing Materials set up a sub-committee some years ago which has issued several reports on replica methods [31]. There is no doubt that in a few years the great deal of investigation going on in 'academic' metallurgy will begin to have an impact on the traditional processes of its technology, especially in connection with the newly developed alloys for special purposes.

#### APPLICATIONS IN SOLID-STATE PHYSICS

In addition to this type of metallurgical studies, the electron microscope is being increasingly used to investigate the ultra-microscopic physical processes which constitute or accompany crystal growth, plastic deformation, and so on. One of the first studies was of slip in metals. R. D. Heidenreich and W. Shockley, and A. F. Brown [32] were able to show that slip lines at a separation of the order of 1000 Å occurred within the macroscopic slip bands. More detailed work by D. Kuhlmann-Wilsdorf and H. Wilsdorf [33] with the SiO replica method has distinguished two types of slip. In pure metals such as aluminium, silver, and copper, slip lines down to 100 Å are formed all over the surface, forming what they call 'elementary structure'. In alpha-brass, on the other hand, neither slip bands nor elementary structure are found, but a mass of randomly arranged slip lines or, in greater distortion, slip steps or terraces [figure 15]. They explain these observations in terms of two different mechanisms of plastic deformation. It is not yet sure, however, that an even better replica technique would not reveal still finer slip lines, possibly in both alloys and pure metals.

At a still finer level of structure, electron microscopy is providing direct evidence of those imperfections which are postulated in the dislocation theory of crystal growth and lattice strength. Growth spirals, a consequence of one type of lattice defect, are indeed visible in some crystals under the optical microscope, but Dawson [34], by using an elegant technique on lamellar crystals of long-chain compounds (figure 13), has provided evidence of their occurrence in the very earliest stages of crystal growth. He is able to

show, by the metal-shadowing technique, whether growth steps are mono- or multi-molecular in height. In some of his electron micrographs the crystals appear to be simple monomolecular sheets, without imperfections, at the edges of which dislocations are formed during later deposition of molecules.

Still more experimental material for checking and extending dislocation theory is provided by direct observation of the molecular units in a lattice. Figure 9 shows the beginnings of a raft or ordered mono-layer of a plant virus, but the more advanced stages of growth are even more informative, as revealed in the beautiful micrographs obtained by R. W. G. Wyckoff and L. W. Labaw [35], using a combined metal-carbon replica technique (figure 12). Many of the micrographs again show a remarkable perfection of structure, considering that they have been dried before replication. When more than one face is exposed the complete crystal structure can be deduced.

Virus particles are about one hundred times greater in diameter than atoms, and the forces between them are different in nature and intensity. It cannot be assumed that in forming crystals they will necessarily obey the same laws as do atoms, and it is important to examine other types of lattice. The next step has now been taken by Menter [36], who has obtained pictures of a small molecular lattice without the intermediary of a replica. He chose the metal phthalocyanines for investigation, because of the favourable disposition of the metal atoms in planes which are almost normal to the flat face of the ribbon-like crystal. When resting on the supporting grid, therefore, the lattice will present what is effectively a set of parallel slits to the electron beam. Diffraction from the  $20\bar{1}$  planes containing the metal greatly outweighs diffraction from the lighter atoms forming the rest of the molecule, so that in favourable orientation a direct image of the lattice is formed (figure 16). Owing to the extreme thinness of the crystals ( $\sim 10$  unit cells) the third Laue condition is so far relaxed that there is considerable latitude in orientation. Micrographs of the compound with platinum give a measured spacing of  $11.97 \text{ \AA}$  for the  $20\bar{1}$  planes, compared with the value of  $11.94 \text{ \AA}$  from X-ray analysis. The agreement is not quite so good for the copper compound, probably because the  $20\bar{1}$  planes are inclined at a greater angle ( $10^\circ$ ) to the normal to the flat face of the crystal. In one micrograph a remarkably clear case of a line dislocation was observed (figure 14), exactly accord-

ing to the book. The metal-free compound, in which hydrogen replaces the metal, gives images of the lattice, although less well pronounced.

The structure of phthalocyanine was already known, but it may well be that electron microscopy will be able to assist in elucidating that of some other substances, suitably loaded with metal atoms. It should now also be possible to test directly theories of the variation of lattice parameters in very small crystals. The observation of lattice vacancies or interstitial material will depend upon a further improvement in resolution.

#### PRACTICAL LIMITATIONS OF ELECTRON MICROSCOPY

So far as lens aberrations are concerned, the modern electron microscope should be able to reach a resolving power of  $2-3 \text{ \AA}$ , making visible individual atoms of high atomic number and the lattices of almost all crystals. The limiting factors are of a different nature: displacement and contamination of the specimen. The former includes thermal and electrical effects due to the impact of the beam on the specimen, mechanical vibration, fluctuations in the electrical supplies, and the effects of stray electric and magnetic fields. It is a matter of detailed design and testing to bring these influences under control or at least to minimize their effect on the image [37]. But even if a resolving power of a few Ångström units were available it would quickly be rendered useless as soon as the electron beam strikes the specimen, owing to the deposition of a blanketing layer upon it. This 'contamination' is carbonaceous and probably comes from residual material on and in the inner walls of the microscope. The rate of deposition is of the order of  $1 \text{ \AA}$  per second, so that structural details near the limit of resolution are rapidly blotted out. It constitutes the greatest single hindrance to attaining in the electron image the resolving power of which the microscope is theoretically capable. The only practicable answer at present is to heat the specimen stage [38], since deposition does not occur if the temperature is above  $200^\circ \text{ C}$ , but this expedient is not possible with biological specimens. The ultimate solution must involve a detailed investigation of the main origin of the contaminating substance, with consequent changes in materials used for the construction of the instrument and in their treatment.

Even when these problems have been solved and a resolving power of a few Ångströms has been demonstrated on selected test specimens, the difficulty will remain that most specimens of interest

provide insufficient contrast for details of this order. Biological specimens at present rarely show resolution better than 20 Å where test preparations of colloidal metal show 10 Å or better. The low scattering power of elements of small atomic number is the reason, and part of the remedy will consequently be the development of specific heavy-metal stains. It will also be of value to eliminate from the imaging beam those electrons which have been inelastically scattered in the specimen and confuse the image owing to the chromatic error of the electron lenses. Correction

of this defect would not appreciably improve contrast, but rejection of the inelastic component would do so. The design of suitable filter-lenses is already practicable [39].

Only after these improvements have been perfected will it be profitable to develop a lens corrected for spherical aberration. Experiments so far made with correction elements [40] make it only too evident that they will introduce new requirements in electrical and mechanical stability. The last lap on the way to a resolving power of 1 Å is likely to be the longest and most troublesome.

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# Book reviews

## THE FUTURE OF MAN

The Foreseeable Future, by Sir George Thomson. Pp. vii + 166. Cambridge University Press, London. 1955. 10s. 6d. net.

This is a fascinating book because of its intimate personal quality. Sir George gives us his forecast of technical advances and of the results of their impact on human society in the near future. His thoughts range over a wide field, and the book is full of shrewd reflections and sly touches of humour. The analytical approach of the physicist, unwilling to leave things as vague qualitative generalizations, keeps peeping out and is seen at its best in the chapter on transport and communications. The simple calculations forecasting the future of travel by air, sea, and land, of interplanetary flight, and of television reveal clearly, even to the layman, the possibilities and limitations of each. Sir George is an optimist and does not allow himself to be worried unduly by the problems of the increase of population and food supply. But he is concerned about man's ultimate future. 'Civilized mankind at present is rather like a child that has been given too many toys for its birthday.' How will he use them, and how will he use the leisure that will come from the automatic factory—in some creative work, or in the pursuit of adventure like space travel? The answer, he thinks, may come from our increasing knowledge of the working of the brain, which may release us from a tangle of hindrances that come from wrongly sorted impressions. 'Man may expect a glorious future.' HAROLD HARTLEY

## EXPERIMENTAL DESIGN

Experimental Design and its Statistical Basis, by D. J. Finney. Pp. xi + 169. Cambridge University Press, London. 1955. 30s. net.

Dr Finney contributes this book to a series for workers in biology and medicine, and his examples are chosen from these fields. But his emphasis is not on elementary descriptions of standard designs. Rather, it gives a penetrating discussion of practical ways of deriving the maximum benefit from experimental work, opening and closing with general chapters on this theme and emphasizing the value of statistical consultation undertaken sufficiently early and thoroughly in a research programme. This applies to industrial and

laboratory experiments, as to all others, and the book will therefore have a general appeal.

Two chapters cover methods of dealing both with observations classified into groups and with actual measurements. Chapters on standard methods of design are illustrated with thorough discussion of examples, and industrial research workers will note with interest comments on the use of designs to compare methods of technique. The chapters on factorial experimentation and sequential methods will certainly be very useful to chemists; interest in biological assay also is by no means confined to pure biologists. Reading will be somewhat easier, naturally, for those who have some basic knowledge of statistical method, but the book should find a place in the libraries of all research departments. G. M. CLARKE

## NUMERICAL ANALYSIS

Numerical Analysis, by Z. Kopal. Pp. xiv + 556. Chapman and Hall Limited, London. 1955. 63s. net.

This volume provides a systematic and comprehensive introduction to the theory and practice of the numerical analysis of functions of a single real variable. Professor Kopal has succeeded in producing a most stimulating and inspiring account of this most important development in mathematics as applied to problems of the real physical world. The subject is presented in a most attractive and charming style, and the individual chapters are enriched with biographical notes which are of very considerable interest and which often throw a great deal of light on the historical development of the subject. The carefully selected problems at the end of each chapter provide a searching examination of the grasp the reader has formed of the subjects treated.

The order of presentation of the subject is polynomial interpolation, numerical integration, and integration of ordinary differential equations. This is followed by an account of boundary value problems as solved by algebraic, variational, iterative, and other methods. After an account of mechanical quadratures, the author concludes by discussing the numerical solution of integral and integro-differential equations. The volume will doubtless come to be one of the standard textbooks on this important subject. G. TEMPLE

## HISTORY OF THE TELESCOPE

The History of the Telescope, by H. C. King. Pp. xvi + 456. Charles Griffin and Company Limited, London. 1955. 50s. net.

The need for a comprehensive history of the telescope has long been felt. Dr King has filled the lacuna by a study exemplary in scholarship and detail; clearly it will stand as an indispensable work of reference and as a source of information unobtainable elsewhere.

A feature rare in historical accounts because of the great difficulty involved, it continues the story to the present day—even including details of radio-telescopes still in construction. The last hundred years of telescope-making occupy more than half the book, so there has resulted an inevitable but unwelcome curtailing of the earlier history. The reader must be warned that the treatment in this book is at an opposite pole to that of the companion volume—'The History of the Microscope' by R. S. Clay and T. H. Court—which was published by the same firm in 1932 and has since become a classic. They treated the microscope from an antiquarian standpoint, giving lists and biographies of known makers, concentrating attention on earlier models, and ending at the invention of the achromatic instrument. Dr King seems more at home in the modern observatory and the library rather than in the museum, and he relies chiefly on printed accounts to illustrate the history of the scientific design. Consequently his treatment of pre-telescopic instruments is weak, and he quite omits the fine and important vellum-tubed telescopes, common in museums but not in literature. Thus he even misses the earliest English telescope, now at Greenwich, made by Jacob Cuningham in 1661.

DEREK J. PRICE

## DIAMOND CRYSTALLOGRAPHY

Microstructures of Diamond Surfaces, by S. Tolansky. Pp. viii + 67. N.A.G. Press Limited, London. 1955. 40s. net.

The transition in recent years of industrial diamonds from the status of a worthless by-product to their role of strategic material in several branches of technology, has attracted the attention of many individuals and laboratories to the remarkable properties of crystalline carbon.

The elegant and useful optical techniques of Professor Tolansky have been applied lately by his school to studies

on the microstructure of diamond surfaces. In a small monograph Professor Tolansky has summarized the results of the investigations he has so ably directed in this field. The volume is written in a manner which will appeal to technical workers in many spheres besides those of optics and crystallography. The lucidity of the text is enhanced by the excellent reproduction of many remarkable photographs selected as illustrations.

The author emphasizes that his book is essentially a preliminary report, and the reviewer is one of many who will eagerly await the future appearance of an enlarged edition, in which we hope advances of knowledge will throw more light on the relationships between diamond surfaces and the properties of industrial stones, the origin of natural diamonds, and factors involved in the recent production of synthetic diamonds.

ROLAND S. YOUNG

#### NUCLEAR PHYSICS

*Nuclear and Radiochemistry*, by G. Friedlander and W. Kennedy. Pp. ix + 468. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London. 1955. 60s. net.

This book discusses the fundamental facts of nuclear physics. To British eyes the title is misleading, but in the United States 'nuclear chemistry' is synonymous with 'transmutation of elements.' Thus only two out of thirteen chapters and a small section on target chemistry deal—by no means fully—with what in Britain would be considered chemical aspects. There is little or nothing about chemical manipulation of highly active materials, about shielding problems, glove-box techniques, remote handling, or even the chemistry of the heavy elements.

As an introduction to the field of radioactivity and nuclear transmutations, however, the book does full justice to its material. Well balanced chapters deal with the structure and the reactions of nuclei as well as with the techniques of radioactive measurement. The chapter on nuclear energy, written before the releases of the Geneva Conference on Atomic Energy (1955), is no longer adequate and will no doubt be rewritten in a future edition. Among the matters discussed are cosmic problems, such as nuclear processes in stars and the formation of the terrestrial elements. A series of appendices on nuclides and their physical properties completes a book which is exceedingly

well written and which can be recommended not only as a textbook for the student, but also as a useful reference book.

E. GLUECKAUF

#### ELECTRON OPTICS

*Optique Electronique, Volume I: Lentilles Electroniques*, by P. Grivet, M. Y. Bernard, and A. Septier. Pp. 184. Bordas, Paris. 1955. Fcs 1450 net.

The present volume is the first of a series of three which will cover the applications as well as the theory of electron optics. It provides a clear and concise account of the principles and properties of magnetic and electrostatic electron lenses. The approach is from comparatively simple physical principles, so that it avoids being a specialist tract and should be understandable by any graduate in physics or mathematics. Where the Germans would offer a *Handbuch* of four times the length, and the Americans an embalmed lecture course starting from elementary definitions, the French by judicious selection have produced what is perhaps the best balanced and most useful treatment of the subject yet to appear. As M. L. de Broglie notes in his preface, the authors are always at pains to keep theory in contact with practical problems. Methods of measurement are given for electron lens properties and electromagnetic field distributions, as well as a full mathematical derivation of ray paths and aberrations. Practical details of the design and construction of electron lenses are included. If electrostatic lenses receive fuller mention than the magnetic type, it is a reflection of the main preoccupation of Professor Grivet's laboratory. The final chapter deals with the recently developed method of 'strong focusing', in preparation for the discussion of particle accelerators in volume three.

V. E. COSSLETT

#### MEDICINE AND NUCLEAR PHYSICS

*Medicina Nucleare*, by A. Perussia. Pp. xii + 877. Il Pensiero Scientifico, Rome. 1954. Lire 7000.

The main feature and the greatest virtue of this book are its directness and simplicity. It is therefore valuable for all readers who, although interested in the practical applications of the isotopic tracers, yet do not command a specialized knowledge of nuclear physics. The radioactive isotope techniques,

already used in many fields of scientific investigation, make it necessary for the research worker to be up to date in the different aspects of these new methods. Often doctors, physiologists, pharmacologists, and even chemists can obtain only a superficial understanding from their readings of the large literature available in this specialized field, and most of the facts related to radioactivity and its effects on matter tend to remain rather hazy. We must be grateful to Professor Perussia and his collaborators for this book, in which a number of intricate ideas are explained clearly and comprehensively, without demanding too wide a knowledge of mathematics and physics from the readers, and yet fully describing the possible applications and methods of radio-biochemistry and the modern developments of radiotherapy. In a book of this scope it is no disadvantage that in the first part some of the subjects of a strictly physical character have been dealt with rather briefly. All who are interested in the use of isotopes as tracers and as therapeutic agents will find this book extremely useful.

MAURIZIO ZIFFERERO

#### GENERAL PHYSICS

*Principles and Applications of Physics*, by Otto Blüh and Joseph D. Elder. Pp. xiv + 866. Oliver and Boyd Limited, London. 1955. 45s. net.

This is a general textbook of physics which, in standard, lies in the field somewhere between the intermediate and the pass degree, and will appeal, in universities and technical colleges, to those who need a simple and comprehensive guide to the subject and to other students, who are going further, as a general introduction. It will also be welcomed by many who, not confronted with examinations, want an up-to-date elementary exposition of the whole field of physics, including recent applications.

The book is notable for the wide ground covered and especially for the brief descriptions of very recent work of which many have heard without knowing very clearly what is in question. Thus transistor and thermistor, photomultiplier tube, ferroelectricity, semiconductor, anti-*g* suit, coated lenses, cosmic rays, the cavity magnetron, the superheterodyne circuit, the electron microscope, supersonics, the Mount Palomar telescope, and many more products of the last twenty years or so

all come in for mention. Not very much is, perforce, said of each, and if there is to be a criticism, it is that the principles are not much stressed, even when they are simple and revealing. Thus we are told of the directional properties of supersonic waves, but little is said of the cause of these properties, although a very useful and general lesson is involved.

To make room for the very modern developments the discussion of certain of the fundamental matters, such as specific heats—and, in fact, the subject of heat in general—suffers somewhat. The standard properties of matter are not very convincingly handled. On the other hand, attention is devoted to the medical applications of physics and to the inanimate aspects of television, while a considerable chapter deals with nuclear physics, including the most modern aspects. The final chapters deal with the philosophy of physics and with the general place of physics in the world of today.

In general the authors have produced an extraordinarily inclusive and very lively book, which will answer satisfactorily the questions provoked by reading in the popular press of the physics of today, if not some of the simpler and more fundamental queries in elementary physics that occur to the occasional reflective mind.

E. N. DA C. ANDRADE

#### THE LAWS OF NATURE

The Laws of Nature, by R. E. Peierls. Pp. 284. George Allen and Unwin Limited, London. 1955. 21s. net.

Is it possible to convey to the ordinary educated man in the limited space of one moderate volume the whole of physics from Galileo to the renormalization of mass and heavy mesons? Professor Peierls has certainly made a gallant attempt. Whether he has succeeded or not the present writer is not quite sure, but he feels pretty certain that if Peierls has failed the thing cannot be done. This is a fascinating book for a physicist to read quickly, seeing the whole of his subject pass in panorama before his eyes, rather as a man may view a familiar country from the air. The book is well written and illuminates the scene with many flashes of wisdom. There is very little mathematics, but such a treatment presupposes the mental attitude of a man who thinks naturally in mathematics. It would be a most interesting experiment if some far-sighted headmaster

would try this book on his classical sixth: if they could grasp it—and there is no knowledge assumed that they would not have had—they would have a better understanding of the meaning of physics than many science graduates. The difficulty of physics lies in the ideas, which sound simple but are deceptively subtle: I have heard a Nobel Prize-winner stumble badly on a bit of dynamics. It is to my mind doubtful if anyone can grasp these ideas quickly; they need time to sink in. Besides Newtonian dynamics there are the ideas of entropy as a measure of disorder, of wave motion, of fields of force and their associated potentials, of electrodynamics as a connected whole, of relativity, of the quantum theory and its relation to probability, to name only a few of the most important.

If a man cannot give time to understand these ideas, how far will a superficial acquaintance with them help him? Perhaps more than the professional teacher of physics is usually inclined to admit. Though he may not really understand the ideas in the sense of comprehending them in the round, he will, one may reasonably hope, see them as outlines, though misty ones, and perhaps most important of all be able to reject many views that are wholly incompatible with them. For the man who wishes to get such a view Professor Peierls' book is admirable.

G. P. THOMSON

#### QUANTUM THEORY OF SOLIDS

Quantum Theory of Solids, by R. E. Peierls. Pp. vi + 229. Clarendon Press, Oxford. 1955. 30s. net.

This volume provides a general introduction to a number of fundamental problems in the quantum theory of solids. The dynamical theory of crystal lattices and phenomena involving the interaction and scattering of photons, to the understanding of which Professor Peierls has made an important contribution, are covered by valuable sections. The chapters on the electron theory of solids, cohesion in metals, transport phenomena, and magnetic properties give a clear presentation of these subjects. The only references to the more practical aspects of the physics of the solid state are contained in the chapter on semiconductors and luminescence. Here it is to be regretted that there is no mention of germanium, because many of the fundamental properties of semiconductors are best exemplified by the results of experimental

work with this important material. The book concludes with a review of the Fröhlich-Bardeen theory of superconductivity and a summary of the difficulties encountered in the theoretical discussion of the model.

The limitations imposed by the simplified models which alone are amenable to theoretical discussion and the assumptions made in the derivations are noted throughout the book, and there are clear statements of the physical significance of the results of the mathematical investigations. These two features will be appreciated by theoretical and experimental physicists alike.

J. W. MITCHELL

#### ORGANIC CHEMISTRY

Schmidt's Organic Chemistry (*seventh edition*, revised and edited by N. Campbell. Pp. xi + 936. Oliver and Boyd Limited, Edinburgh and London. 1955. 35s. net.

Schmidt's original work, published in 1906, was called *Kurzes Lehrbuch der organischen Chemie*. The third (1922) German edition was already a formidable affair, and the present volume represents the result of repeated revision of the first English edition, published in 1926. It contains many remnants of the first translation, and Dr Campbell has done remarkably well to keep the book from outgrowing its strength. The revisions include sections on the structural applications of ultra-violet and infra-red spectroscopy, the conformation of cyclohexanes, nucleotides, nucleic acids, nucleophilic and homolytic substitution of aromatic compounds, polysaccharides, and other topics of current interest.

It is a pity that some benzene rings are written without three double bonds while others, sometimes on one and the same page, are written in what is at the moment the accepted style. As is almost inevitable in so large a work, some points have escaped correction. The account of the chemistry of urea is not particularly up to date. The stereochemistry of the tartaric acids might have been given more space, if only in view of recent work on absolute configurations. No mention is made of how formamide is made, or how it differs from true acid amides. On the whole, however, the book presents a balanced view of the more important branches of organic chemistry.

There is an author index as well as a good subject index. The volume is excellently printed.

E. E. TURNER

## CHEMISTRY OF HYDROCARBONS

The Chemistry of Petroleum Hydrocarbons, edited by B. T. Brooks, C. E. Boord, S. S. Kurtz, and L. Schmerling. Volume 1, pp. viii + 664; Volume 2, pp. vi + 448; Volume 3, pp. vii + 690. Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London. 1955. 144s. net, 108s. net, and 144s. net respectively.

It is hardly possible in a brief review to convey an adequate idea of the richness of the contents of these three volumes. The fifty-nine chapters, by some sixty different authors drawn mainly from oil companies and teaching and research institutions, several by one or other of the distinguished editors, cover most conceivable aspects of hydrocarbon chemistry, the hydrocarbons including paraffins, olefins, alicyclics (naphthenes), aromatics, and the hybrid classes. The first six chapters deal with the compositions of petroleums and their possible origin. The next ten are concerned with methods of separation of the components and with analysis and identification, e.g. with extractive and azeotropic distillation, infra-red and Raman spectra, and mass spectroscopy. Five chapters deal with the synthesis of hydrocarbons, including one on the Fischer-Tropsch process, and these are followed by ten important chapters on the thermal treatment of the hydrocarbons, thermal and catalytic cracking, aromatization, reforming, hydro-forming, 'platforming.' The theory of catalytic cracking is discussed in a fascinating manner by B. S. Greenfelder, making free use of the carbonium ion theory. Other chapters discuss different aspects of the oxidation of hydrocarbons, and a number of miscellaneous chapters deal with halogenation (including fluorination), nitration, isomerization, and polymerization of olefins. A long chapter on aromatic substitution (114 pages) is planned in an unusual but interesting way, with special emphasis on alkylation. It is followed by one on industrial applications of the alkylation of aromatic hydrocarbons, discussing particularly the production of ethylbenzene from benzene and ethylene (for styrene) and of higher alkylbenzenes (for the manufacture of detergents). The emphasis throughout is on scientific principles, not technological practice.

With few exceptions the contributions are clearly written and their subject matter well arranged and presented; many of them, with their criti-

cal accounts of the results of recent research, must be of interest to a far wider circle of chemists than those engaged in the petroleum industry. The reviewer had a strong impression that the utility of the work would have been enhanced by an introduction explaining the layout of the work, more cross-references, and, for the reader not well versed in the language of oil chemists, a glossary of technical terms and abbreviations.

E. H. RODD

## PHYSICAL CHEMISTRY

Physical Chemistry, by Farrington Daniels and Robert A. Alberty. Pp. vii + 671. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London. 1955. 52s. net.

This is a sound introduction to physical chemistry for university students. Its chief merits are a very clear and concise exposition of the main experimental facts and their interpretation, which can be recommended to students who find the subject difficult; there are selected references to more advanced books and to original papers for those whose interest is aroused. Each chapter contains a number of calculations worked out as examples and about thirty numerical problems, some with, and some without, answers.

After a discussion of the states of matter, eight chapters are devoted to thermodynamics. The approach is a functional one, the phase rule is proved and applied to systems containing up to three components, and the treatment of chemical equilibria includes the third law and a brief account of statistical mechanics. In the section on electrochemistry a distinction is admitted between the experimental concept of electrode potential and the derived ideas of oxidation and reduction potentials; there is thus hope of reconciliation between the different conventions in use on the two sides of the Atlantic. Colloids and nuclear chemistry are well covered, but the chapter on chemical kinetics might have been brought more fully up to date. Relatively little space is given to molecular structure, and the unifying role of quantum theory is not emphasized.

K. W. SYKES

## ANALYSIS OF DRUGS

The Quantitative Analysis of Drugs (second edition), by D. C. Garratt. Pp. xv + 670. Chapman and Hall Limited, London. 1955. 70s. net.

The first edition of this book, which was published in 1937, appeared under the title 'Drugs and Galenicals: Their Quantitative Analysis'. The revision of the earlier text has increased the number of pages by over 50 per cent, the enlargement being accounted for mainly by the introduction of new matter in some of the monographs previously presented, by the addition of over thirty new monographs, by the inclusion of a new chapter on physical methods, and by the incorporation of two new appendices covering respectively 'Extraneous matter in food and drugs' and 'Titration in non-aqueous solvents'. A cross-indexed supplement is also included to correlate the text with changes in the subject-matter of the British Pharmaceutical Codex which were introduced in the new edition, which appeared while Garratt's book was in press.

The wise drug analyst will follow the advice given by the author in his preface to check, whenever possible, the results obtained by one method by applying another, and preferably fundamentally different, analytical technique. As an aid to the adoption of this recommendation, the many methods abstracted from the British Pharmacopoeia or British Pharmaceutical Codex which appear in the monographs of Garratt's book are liberally supplemented by other procedures. 'The Quantitative Analysis of Drugs', in which misprints are scarce, is a useful adjunct to these two standard works and can be recommended to chemists who are called upon to make analyses of drugs. In their possession it is likely to spend more time on the laboratory bench than on the library shelf.

A. J. AMOS

## PALAEONTOLOGY

Stratigraphical Palaeontology (second edition), by E. Neaverson. Pp. xii + 806. Clarendon Press, Oxford. 1955. 105s. net.

The second edition of Dr Neaverson's well known 'Stratigraphical Palaeontology' has been greatly enlarged (from 525 to 806 pages) by the interpolation of sections dealing with extra-British marine faunas grouped under 'faunal regions.' The sections on British faunas to which these have been added seem to be only slightly modified, and the result is a presentation that remains essentially insular. A few new figures have been prepared, together with a number of small-scale maps 'to indicate

the distribution of facies in certain critical areas.' It is a pity that the trilobite figures at least could not be redrawn, for many of these are incorrect in detail, and even the magnifications given are often unreliable, but other groups of fossils seem better served.

The single-handed compilation of an advanced textbook such as this, surveying the whole succession of faunas from Cambrian to Pliocene on a world scale, is a vast undertaking. Inevitably specialists will find matters for criticism in the selection, content, and balance in particular sections, and inevitably also such a work will be more or less out of date by the time it is published. In the present instance, some wartime and post-war references are included in the literature lists, but it does not always follow that they are fully incorporated in the text. O. M. B. BULMAN

#### HORMONES IN REPRODUCTION

*British Medical Bulletin, Volume 11, No. 2 (Hormones in Reproduction), edited by A. S. Parkes. Pp. 83 + 170. Medical Department, The British Council, London. 1955. 15s. net.*

The time of publication of this issue of the British Medical Bulletin was well chosen. It was fifty years from the day in 1905 when Marshall and Jolly gave a paper to the Royal Society on 'The ovary as an organ of secretion'. Their recognition at that time of the functions of the follicular and luteal hormones set reproductive endocrinology upon a course of astonishing development. Introduced by a preface by A. S. Parkes, a neat historical summary of those discoveries that hastened progress, the papers by authorities in Britain and the Dominions are confined mainly to recent advances in research upon the reproductive system. They offer a very full account of certain topics: the reaction of the reproductive system to external stimuli and neurohumoral effects; the physiology and chemistry of gonadotrophins, oestrogens, and androgens; mammary growth, problems of fertility in man and farm animals; chemical and biological assays of sex hormones; and the effects of the adrenal and posterior pituitary gland upon reproduction. They are valuable for their full picture of knowledge of the reproductive systems of several species, and for the presentation of many intriguing and puzzling questions that remain unanswered.

J. R. P. O'BRIEN

#### OCCUPATIONAL MEDICINE

*The Diseases of Occupations, by Donald Hunter. Pp. xv + 1046. English Universities Press Limited, London. 1955. £5 5s. net.*

At long last Dr Donald Hunter has given us the benefit of his wide knowledge of occupational medicine in a remarkable textbook, which must surely become in Britain the standard work on this subject. This is a history book, a teacher of clinical medicine, and a text of public health; it will be of value to medical students, nurses, general practitioners, industrial medical officers, and consultants.

In a work of this size there are inevitably a few omissions; for example, there is no mention under occupational cancers of the risk of cancer of the lung in gas workers, nor of the comprehensive review by Hueper (1953) of occupational cancer. The account of the examination of young entrants into industry is out of date and does not mention the Factory Act of 1948. Perhaps some mention could have been made of the hazards of student life and the part played by the student health services, also the value of epidemiology in the study of occupational disease and the work of the industrial psychologist. However, these are trivial matters, and are probably due to the fact that Dr Hunter writes as a general physician practising in a great London teaching hospital. One notable feature of the book is the large number (438) of very fine illustrations. W. HOBSON

#### TUBERCULOSIS AND LEPROSY

*Experimental Tuberculosis (with an Addendum on Leprosy), edited by G. E. W. Wolstenholme and Margaret P. Cameron, assisted by Cecilia M. O'Connor. Pp. xii + 396. J. and A. Churchill Limited, London. 1955. 42s. net.*

Tuberculosis is still one of the greatest threats to the health of mankind, and although modern treatments with antibiotics and chemotherapy happily continue to lessen dramatically the mortality from the disease, its incidence continues as high as ever.

In order to focus attention on the many problems outstanding in this field the Ciba Foundation called together, under the chairmanship of Dr A. D. Rich, a group of about forty international experts interested in fundamental research on both the tubercle bacillus and the host. Their papers and the important discussions,

together with a small symposium on closely related problems in leprosy, are now presented in book form.

A wide variety of topics, chemical, biological, and immunological, were discussed. Two points were outstanding in these discussions, one being the astonishing complexity of the chemistry of the bacillus and the other the almost complete lack of precise biochemical knowledge regarding the mechanism of hypersensitivity reactions and of acquired immunity. Scientists interested in any aspect of infectious disease will find much food for thought in this book, while young medical scientists looking for a major topic for study will hardly fail to get many new ideas. A study of the relationship between lipopolysaccharides and immunity offers an immediate challenge.

M. STACEY

#### RESEARCH FILMS

*Research Films in Biology, Anthropology, Psychology and Medicine, by Anthony R. Michaelis. Pp. xvi + 490. Academic Press Inc., New York; Academic Books Limited, London. 1955. \$10.*

No worker in the fields covered by this book who is using cine-film, or intends to use cine-film, as a research technique can afford to be without Dr Michaelis's monumental work. The reference list of authors of scientific papers, books, and research films, containing well over 1500 references and occupying 90 pages, is alone worth the money. Not only does this book bring us up to date, it provides the only really complete account in English of the history of the research film in the field of the natural sciences.

A most valuable feature of this book is that it includes techniques from a number of related fields set out in an orderly and comprehensive way so that those working in psychology may learn from the experience of medical research workers, and so on. The practical possibilities of the interchange of information and experience have hardly existed before, except on a limited and national basis. Many who have not ventured to use films in research because of inexperience and the lack of expert guidance will be encouraged to use this most neglected but useful technique. Those who have been sceptical of the value of the film as a medium for recording and analysis will be completely convinced by the mass of evidence which is given here.

H. R. HEWER

# Some books received

(Note. Mention of a book on this page does not preclude subsequent review.)

## ASTRONOMY

Making and Using a Telescope, by H. P. Wilkins and P. Moore. Pp. 160. Eyre and Spottiswoode (Publishers) Limited, London. 1956. 12s. 6d. net.

## BIOLOGY

Pelican in the Wilderness. A Naturalist's Odyssey in North America, by F. F. Darling. Pp. 380. George Allen and Unwin Limited, London. 1956. 25s. net.

## BOTANY

Bibliographie der Pflanzenschutzliteratur 1951, edited by J. Bärner. Pp. xliv + 420. Biologische Bundesanstalt für Land- und Forstwirtschaft, Berlin. 1955. DM 38 net.

Cultures Tropicales I. Plantes Vibrières, by R. Cerighelli. Pp. xxxv + 635. J.-B. Baillière et Fils, Éditeurs, Paris. 1955. Fcs 4800 net.

Species Studies in the British Flora. B.S.B.I. Conference Reports, Number 4, edited by J. E. Lousley. Pp. 186. The Botanical Society of the British Isles, London. 1955. 20s. net.

## CHEMISTRY

Lehrbuch der Organischen Chemie, Volume 3/4, by H. Beyer. Pp. xvii + 690. S. Hirzel Verlag, Leipzig. 1955. DM 22.50 net.

Les Lacunes des Cristaux et leurs Inclusions Fluides, by G. Deicha. Pp. 126. Masson et Cie., Paris. 1955. Fcs 950 net. Lithium Aluminium Hydride in Organic Chemistry, by V. M. Micovic and M. L. Mihailovic. Pp. xi + 193. Serbian Academy of Sciences, Belgrade. \$3 net.

Nuclear Level Schemes A = 40 - A = 92 (covering the Elements Ca-Zr), by K. Way, R. W. King, C. L. McGinnis, and R. van Lieshout. Pp. xx + 221. National Academy of Sciences, National Research Council, Washington, D.C. 1955. \$1.75 net.

Organic Syntheses, Volume 35, edited by T. L. Cairns. Pp. vi + 122. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London. 1955. 30s. net.

Porphyrin Biosynthesis and Metabolism (a Ciba Foundation Symposium), edited by G. E. W. Wolstenholme and E. C. P. Millar. Pp. xii + 308. J. and A. Churchill Limited, London. 1955. 30s. net.

Principles of Organic Chemistry (second edition), by James English, Jr., and H. G. Cassidy. Pp. xiii + 469. McGraw-Hill

Book Company Inc., New York; McGraw-Hill Publishing Company, London. 1956. \$6.50 net.

Resonance in Organic Chemistry, by G. W. Wheland. Pp. xiii + 846. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London. 1955. 120s. net. Structure Reports for 1942-44, Volume 9, edited by A. J. C. Wilson. Pp. viii + 448. Published for the International Union of Crystallography by A. Oosthoek's Uitgevers Mij., Utrecht. 1955. Fl. 65 net.

## GENERAL

Clays and Clay Minerals (Proceedings of the Second National Conference on Clays and Clay Minerals), edited by A. Swinford and N. Plummer. Pp. viii + 504. National Academy of Sciences, National Research Council, Washington, D.C. 1954. \$4 net.

Cybernetics (Transactions of the Tenth Conference, April 22-24th, 1953), edited by H. von Foerster. Pp. 100. Sponsored by the Josiah Macy, Jr., Foundation, New York. 1955. \$2.75 net.

Gestalter Unserer Zeit. Forscher und Wissenschaftler im Heutigen Europa, Volumes 3 and 4. Physiker, Chemiker, Astronomen, Erforscher der Erde, Mathematiker, Mediziner, Biologen, Anthropologen. Volume 3, pp. 379; Volume 4, pp. 339. Gerhard Stalling Verlag, Hamburg. 1955. DM 16.80 net per volume.

The Mechanical Properties of Textile Fibres, edited by R. Meredith. Pp. xii + 333. North-Holland Publishing Company, Amsterdam. 1956. 61s. net.

Physical Properties of Wool Fibres and Fabrics. Volume 2, Wool Research. Pp. vi + 234. Wool Industries Research Association, Leeds. 1955. 30s. net.

Sixième Rapport Annuel, 1953. Pp. 229. Institut pour la Recherche Scientifique en Afrique Centrale, Brussels. 1956. Fcs 80 net.

Der Tropische Regenwald, by E. Bünning. Pp. viii + 118. Springer-Verlag, Berlin. 1956. DM 7.80 net.

## GEOLGY

Précis de Géologie (second edition), by L. Moret. Pp. viii + 669. Masson et Cie., Éditeurs, Paris. 1955. Paper covers, fcs 2400 net; bound, fcs 3000 net.

## MEDICINE

Ergebnisse der Medizinischen Grundlagenforschung, Volume 1, edited by

K. F. Bauer. Pp. vi + 855. Georg Thieme Verlag, Stuttgart. 1956. DM 129 net.

German Medical Journal, Volume 1, No. 1, January 1956, edited by G. R. Graham. (Monthly English Language edition of the Deutsche Medizinische Wochenschrift, edited by L. Heilmeyer.) Pp. 36. Georg Thieme Verlag, Stuttgart. 1956. Subscription per year DM 17.60 net. Speicherung. Stoffanreicherung im Retikuloendothel und in der Niere, by N. Jancsó. Pp. 468. Akadémiai Kiadó, Budapest. 1955. 130 Forint.

## METALLURGY

Chromium Nickel Austenitic Steels, by F. H. Keating. Pp. x + 138. Butterworths Scientific Publications, in association with Imperial Chemical Industries Limited, London. 1956. 25s. net.

## PHYSICS

The Analytical Theory of Heat, by J. Fourier, translated, with notes, by A. Freeman. Pp. xxiii + 466. Dover Publications Inc., New York. 1955. \$1.95 net.

Annual Review of Nuclear Science, Volume 5, edited by J. G. Beckerly. Pp. ix + 448. Annual Reviews Inc., Stanford, California. 1955. \$7 net.

Atoms and the Universe, by G. O. Jones, J. Rotblat, and G. J. Whitrow, with a prefatory note by Sir John Cockcroft. Pp. 254. Eyre and Spottiswoode (Publishers) Limited, London. 1956. 25s. net.

Boundary Layer Effects in Aerodynamics. (Proceedings of a Symposium held at the National Physical Laboratory on 31st March and 1st April, 1955.) Pp. xiv + 396. Her Majesty's Stationery Office, London. 1956. 30s. net.

Champs de Vecteurs et de Tenseurs. Introduction à l'Électro-Magnétisme, by E. Bauer. Pp. vii + 204. Masson et Cie., Éditeurs, Paris. 1955. Fcs 2200 net.

Mass-Transfer Operations, by R. E. Treybal. Pp. ix + 666. McGraw-Hill Book Company Inc., New York, 1955. \$9.50 net.

Surveys in Mechanics. The G. I. Taylor Seventieth Anniversary Volume, edited by G. K. Batchelor and R. M. Davies. Pp. 475. Cambridge University Press, London. 1956. 50s. net.

## ZOOLOGY

Principles of Embryology, by C. H. Waddington. Pp. x + 510. George Allen and Unwin Limited, London. 1956. 45s. net.

# Notes on contributors

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Faraday Research Laboratory, but in 1952 resigned, like his predecessor. He maintains close connection with colleagues overseas, and is *Membre Correspondant de l'Académie des Sciences, Institut de France*. He is known for the clarity of his exposition of science, both in writing and by lectures.

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## E. B. FORD,

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Is Reader in Genetics and Director of the Genetic Laboratories at Oxford. He has researched especially on the genetics of natural populations, and on the experimental study of evolution by a combination of ecological and laboratory methods. In this work he has made considerable use of the Lepidoptera (butterflies and moths). He has, in addition, worked on the chemistry of their wing pigments in relation to classification. He has devoted much attention to polymorphic characters and their special evolutionary properties; he was the first to treat the human blood groups as examples of polymorphism. For scientific and other purposes he has travelled extensively in Europe, the Near and the Far East, Australia, New Zealand, and the United States.

## V. E. COSSLETT,

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Was born in 1908 and was educated at Cirencester Grammar School and the University of Bristol. After periods of research in Berlin and Bristol he became lecturer in physics at Faraday House Electrical Engineering College, London, at the same time doing research at Birkbeck College. In 1939 he was appointed Kedney Fletcher-Warr Research Student of London University and during the last war became temporary lecturer in the Electrical Laboratory, Oxford. In 1946 he went to Cambridge as an I.C.I. Fellow and three years later was appointed to his present position as University Lecturer in Physics. In all these appointments his primary interest has been in electron optics, on which he has published several books and a large number of papers.

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